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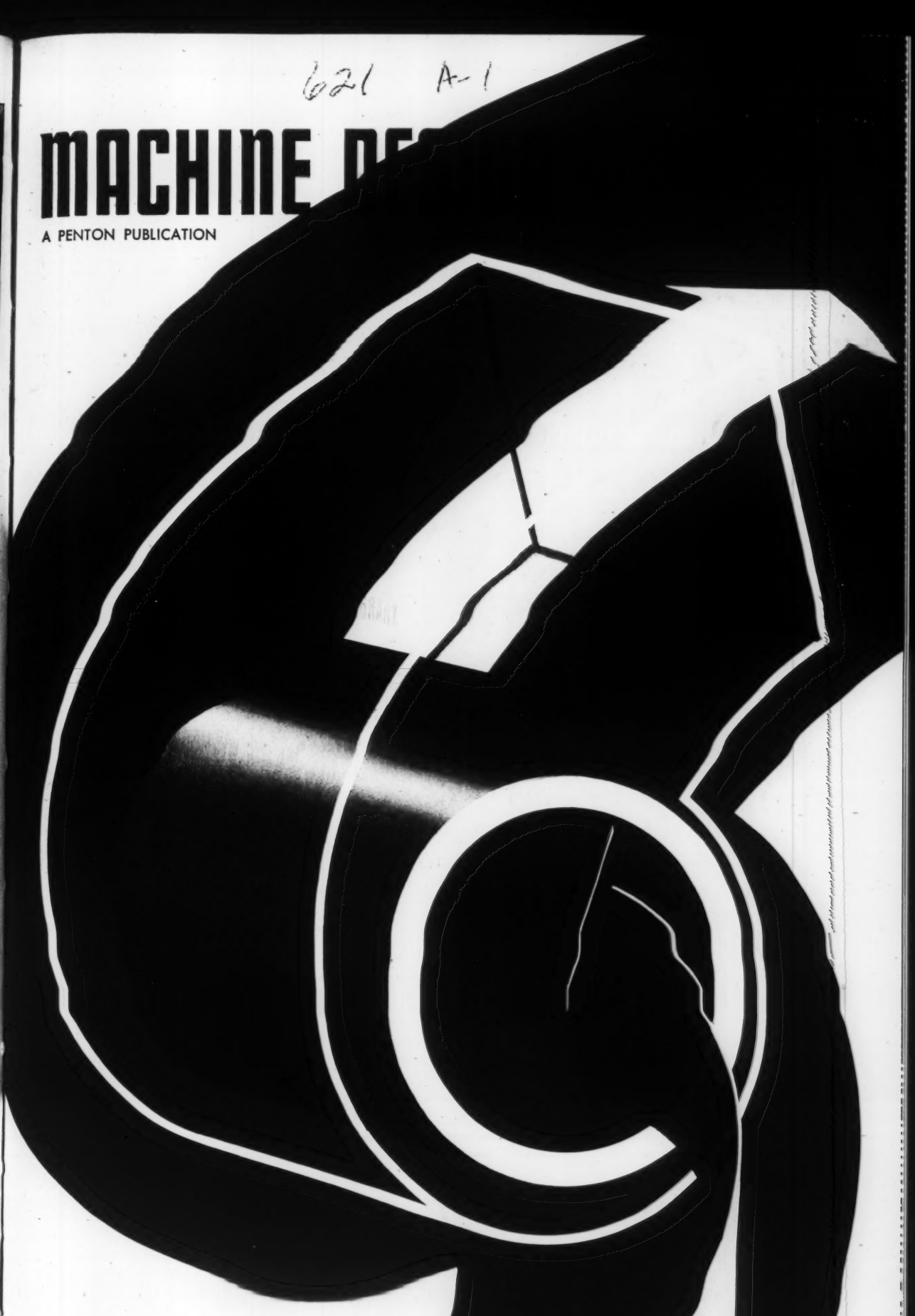
MACHINE DE

A PENTON PUBLICATION



Air-Circuit Design

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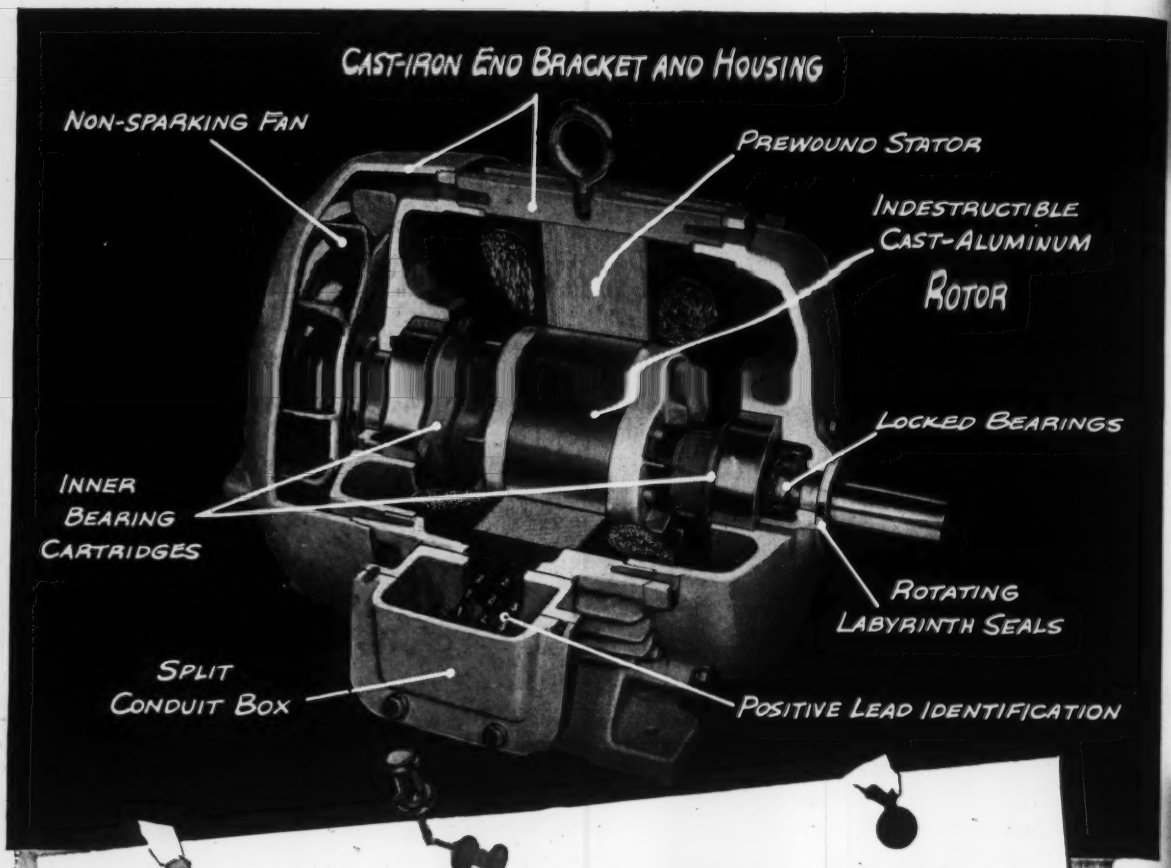
FARNSWORTH



Are you getting all these extras in the motors you buy?

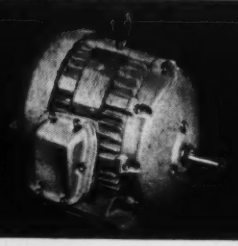
Louis Allis gives them to you in the new L. A. enclosed and explosion-proof motors

For years, Louis Allis has specialized in special motors for many of industry's toughest drive problems. Such installations call for extreme care in both motor design and manufacture—care that has become a habit with us. We build our enclosed and explosion-proof motors with the same special care.

What does this mean to you? It means that you get a motor with extra features—a motor that runs better, lasts longer. Here are a few of the extra reasons why:

- These new motors carry Underwriters' label for use in four groups of hazardous locations—Class I, Group D, and Class II, Groups E, F, and G. This four-group approval for a single motor simplifies your stocking problem.
- New, exclusive phenolic impregnating varnish provides high thermal and chemical resistance. It remains resilient and resists aging, prolonging the life of the motor.
- Inner bearing cartridges lock bearings to end bracket and form explosion-quenching seal along the shaft. Inner race of bearing locked to shaft, reducing end play—an extra quality feature.
- Rotating labyrinth seals keep dirt and moisture out of the bearings—keep grease in.

There are many other features such as a new diagonally split conduit box, sturdy cast-iron construction, positive lead identification, non-sparking fan. Our new bulletin No. 1700 shows why you get extra value for your dollar in a Louis Allis explosion-proof motor. Write for your copy.



New LA line explosion-proof motors are available in rerated frame sizes 182 through 326U, and in ratings of 1 to 30 hp, 3 phase, and 1 to 5 hp, single phase. Also available with Underwriters' approval for Class I, Group C hazardous locations.

EP-102

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New Ross controls
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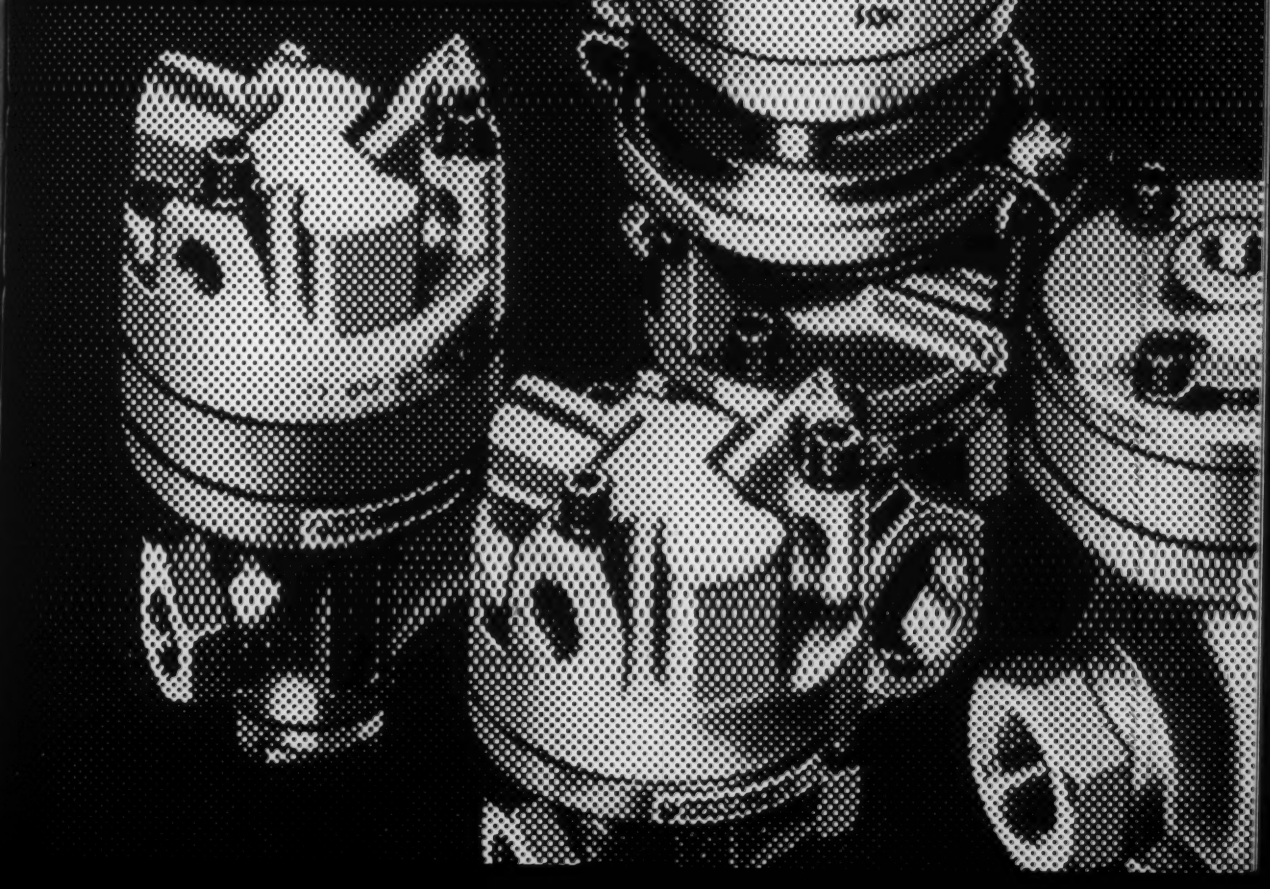

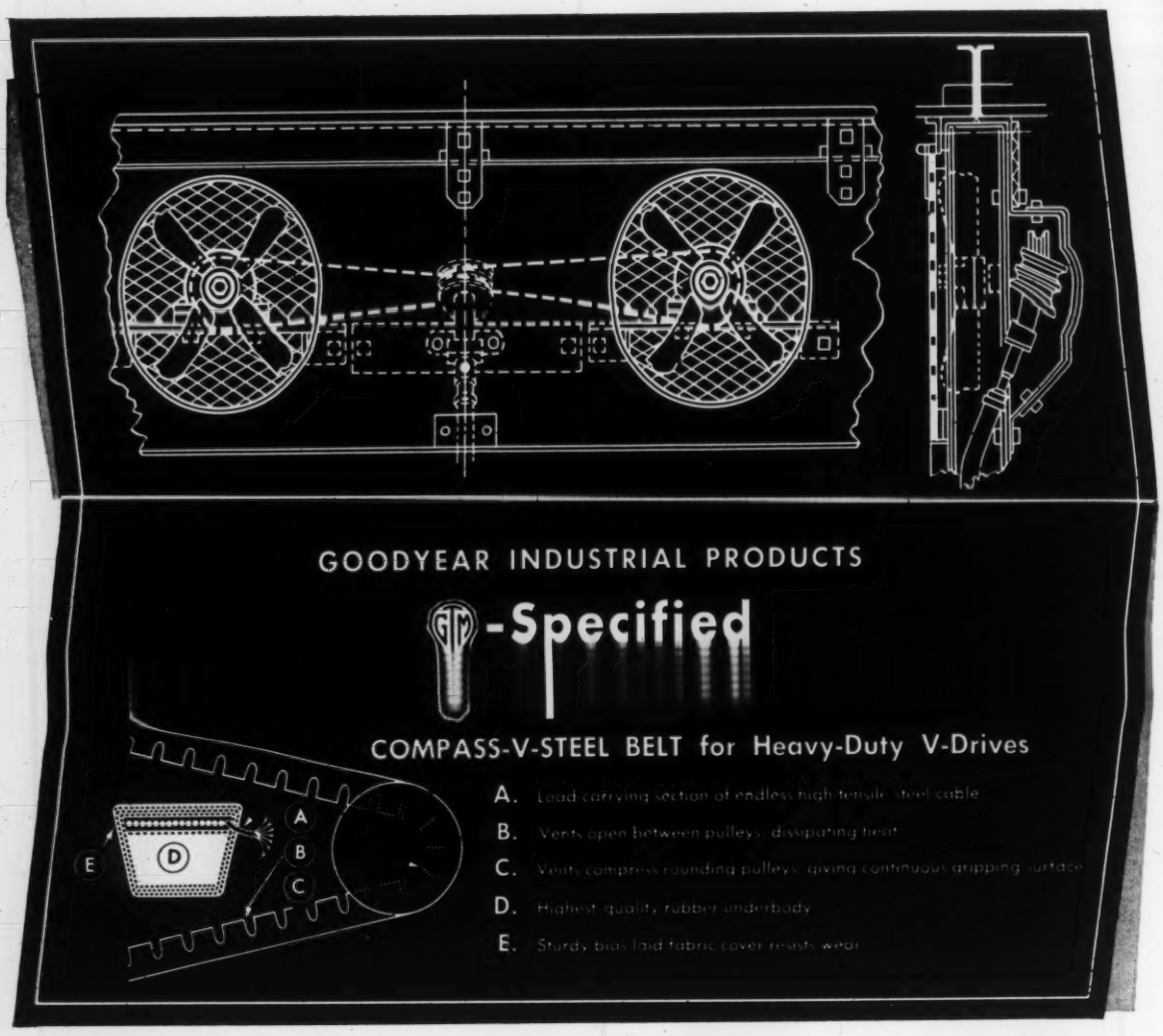
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COMPASS-V-STEEL BELT for Heavy-Duty V-Drives
A. Load carrying section of endless high-tensile steel cable
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A
B
C
D
E

NO BREAKDOWN THROUGH BELT FAILURE

in 2 years on 6,000 drives

BLUEPRINTED above is the tough, quarter-twist drive on the air circulators of a refrigerated railroad car. Two such drives are located over the ice bunkers at the ends of the car. Their job is to equalize the temperature throughout the car by blowing cold air toward the center. They must be reliable, since any breakdown could mean costly damage to a perishable cargo.

To help them design the most dependable drive possible, a bunker maker called in the G.T.M. — Goodyear Technical Man — who recommended a change in sheaves and the use of COMPASS-V-STEEL Belts. Today, after over two years of across-the-country service, no breakdowns because of belt failures have been reported on 3,000 cars — 6,000 drives — 12,000 belts.

If you need a truly reliable V-belt for a drive involving heavy loads, shock loads, speeds of 10 to 10,000 feet, limited space or unusual heat, call in the G.T.M. or your Goodyear Distributor. Let him give you the full story on COMPASS-V-STEEL Belts — the stronger, more efficient belts that have proved themselves on over 5,000,000 critical drives. Or write Goodyear, Industrial Products Division, Akron 16, Ohio.

YOUR GOODYEAR DISTRIBUTOR *can quickly supply you with Hose, Flat Belts, V-Belts, Packing or Rolls. Look for him in the yellow pages of your Telephone Directory under "Rubber Products" or "Rubber Goods."*

Compass—T. M. The Goodyear Tire & Rubber Company, Akron, Ohio

GOODYEAR

THE GREATEST NAME IN RUBBER

—ITEM 505—

For More Information Circle Item Number on Yellow Card—page 19

THE PROFESSIONAL JOURNAL FOR ENGINEERS AND DESIGNERS

MACHINE DESIGN

June 28, 1956
Volume 28—No. 13

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Why should you use valuable floor space to make parts like these?

FERRULES
for desk and chair legs, pipes, tool handles, cutlery handles and pencils, etc.

EYELETS
for all types of industrial fastening applications

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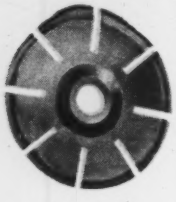
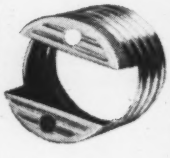


STAMPED PARTS
of every description, including washers of heavy or light metal



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—ITEM 506—

Engineering News Roundup

Epoxy Electrical Insulation Made in Tape Form

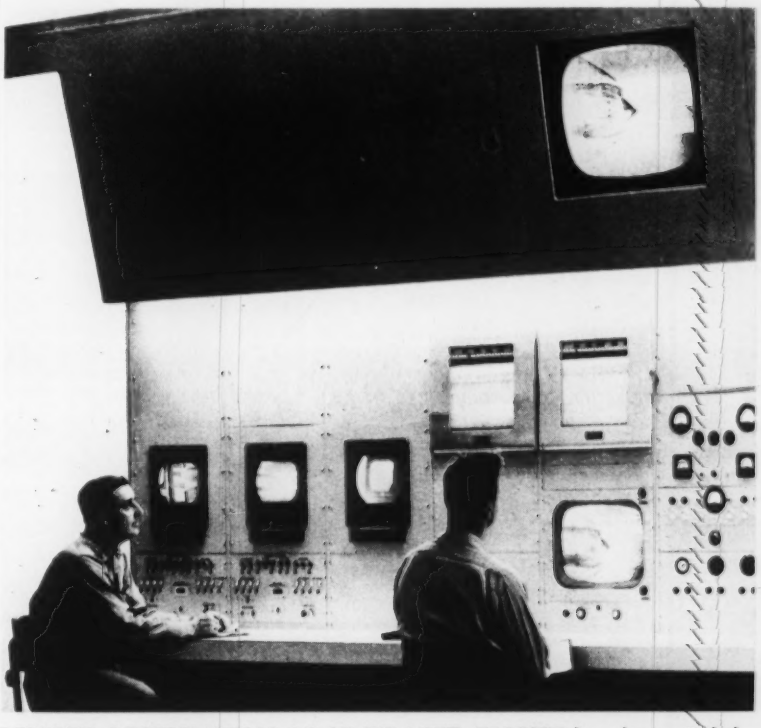
Glass Cloth and Nonwoven Mat Are Impregnated with Resin

ST. PAUL, MINN. — Epoxy resins are now available in tape form for use as electrical insulation. Minnesota Mining and Mfg. Co. announces its Scotchcast resin tapes as the first to provide the properties of epoxy resin in this form.

One tape is made of a glass cloth and the other, of a nonwoven polyester mat. Both are impregnated with uncured thermosetting epoxy resin. After an oven cure, the resin sets into a hard, homogeneous mass around the protected piece. The tapes feel smooth and plastic at room temperatures and leave no residue or pigment on workers' hands.

The tapes have dielectric strength of about 1000 v per mil

and volume resistivity of 10^{12} ohms at 96 per cent RH. They were designed to meet Class B electrical insulation performance requirements. Uses include insulating of coils or conductors; insulating field windings by curing them in their slots; wrapping torroidal windings; forming channels of L and V-shapes; anchoring transformer leads; and as outer covers, interlayer and interwinding insulation in transformers.



REMOTE OBSERVATION OF SIMULATED FLIGHT is a feature of the new NACA wind tunnel at Lewis Flight Propulsion Laboratory, Cleveland. Three RCA industrial television cameras are trained on models in the 10 by 10 ft tunnel. Events are watched on four 24-in. monitors, 250 ft from the test section. Normally, two cameras view schlieren systems and the third views the model or auxiliary equipment. Mach number range in the tunnel is 2.0 to 3.5. Tests may simulate altitudes from 49,000 to 160,000 ft.

Civil Applications Seen For Missile Technology

MOFFETT FIELD, CALIF. — Technological developments stimulated by military necessity rapidly find their way into civilian use, and current research on missiles holds the same prospects. These observations recently led Mr. Hall L. Hibbard, vice president and general manager of Missiles Systems Div., Lockheed Aircraft Corp., to forecast benefits from present programs. Mr. Hibbard spoke at a national convention of the Aviation Writers' Association.

He noted that the wing of the World War II P-38 fighter had become the pattern for the wing of the Constellation transport. More recently, the wing of the F-104 Starfighter came from a missile that has been flown for some time. In turn, the F-104 wing will be used on future transports that will cruise at supersonic speeds.

"I think we will see mail rockets that will take mail across the nation or around the world at tremendous speeds," Mr. Hibbard said. "I think also we will see freight rockets for premium express. The slow freight will go by prop-jet at rates that will be lower than any of today's methods.

"Another development of missile

technology that will be directly applicable to civilian purposes will be the satellite. . . There are a lot of important practical applications for a satellite, and I would like to mention a few:

"Navigation. When we put up our own ideal celestial reference points, built to be visible to radar when stars are not visible, positioned to be exactly where we want them instead of where they appear to be, then we will have navigation down to an exact science.

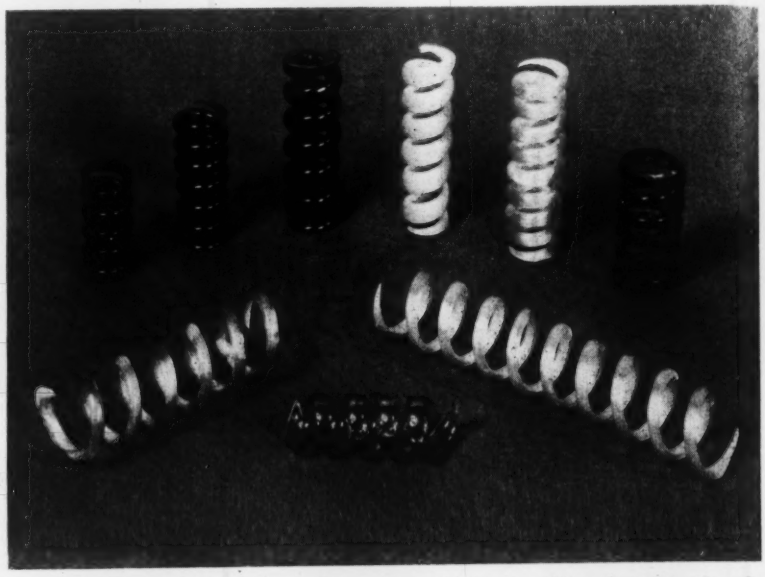
"Communication. With properly placed satellites to reflect or broadcast signals, the old line-of-sight limitation on television and other high frequency electronic phenomena will be a thing of the past. We will be able to beam programs or communications to any spot on earth.

"Meteorology and climatology. People have made fun of every weather forecaster since Noah, . . . but put some satellites up where they can observe the whole panoramic sweep of the weather as it forms and moves, and the weatherman will have the last laugh. . . . Moreover, there is a good possibility that from these vantage points on the edge of space, we can learn enough about cosmic rays, solar phenomena, magnetic storms, meteoric dust, and other phenomena to forecast long range weather cycles and maybe even do something about them.

"I think missile technology is going to lead to lots of new electronic equipment that will be smaller, better, and much cheaper. . . . I think you can confidently anticipate a watch-pocket television set someday, instant communication with almost any place you might wish, robots doing the housework in the most modest homes.

"Another. . . technique that will affect us all is computing and data processing. . . . I mentioned one example of a civilian application here—air traffic control. Others can be ground traffic control, business controls, and automatic production. . . . They may lead to new sources of knowledge of man and his behavior, even new leases on life itself.

"Space flight, or even fully practical satellites, call for new energy sources of much more effective applications of present sources. . . . And the missile people, due to the simplifying of our problems with no humans aboard, may perfect the fully effective application of nuclear, solar, and other energy well before it is done on land or in conventional aircraft."



Plastic springs formed by drawing resin-soaked glass fibers into plastic tubing, then curing the assembly while wrapped in helix form. Springs are nonmagnetic, corrosion resistant, and can be produced in a range of colors.

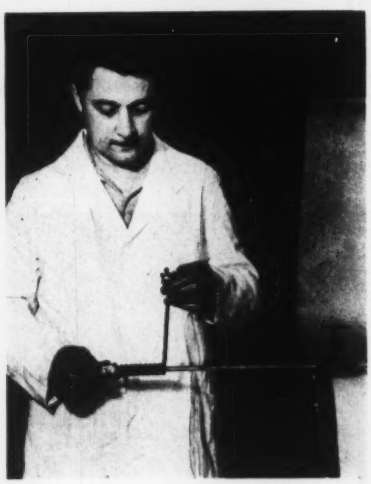
Special-Purpose Springs Can Be Made of Plastic

Glass and Resin Parts Offer Range of Properties

WASHINGTON, D. C.—A procedure for making plastic springs has been developed by the National Bureau of Standards in work sponsored by the Army Ordnance Corps. The springs are formed from glass fiber-reinforced resin and have mechanical properties said to be suitable for a wide range of applications.

The polymeric materials used in the novel springs are nonmagnetic and have low electrical and thermal conductivity. They can be molded directly to final dimensions without the development of any considerable internal stress. They are highly corrosion resistant, light in weight, and available in a broad range of colors.

The most successful procedure uses vinyl chloride-vinyl acetate copolymer tubing having a ¼ or 3/16-in. inside diameter and a



Plastic tubing filled with resin-soaked glass fibers and wrapped around a mandrel is placed in an oven to cure.

Front Cover

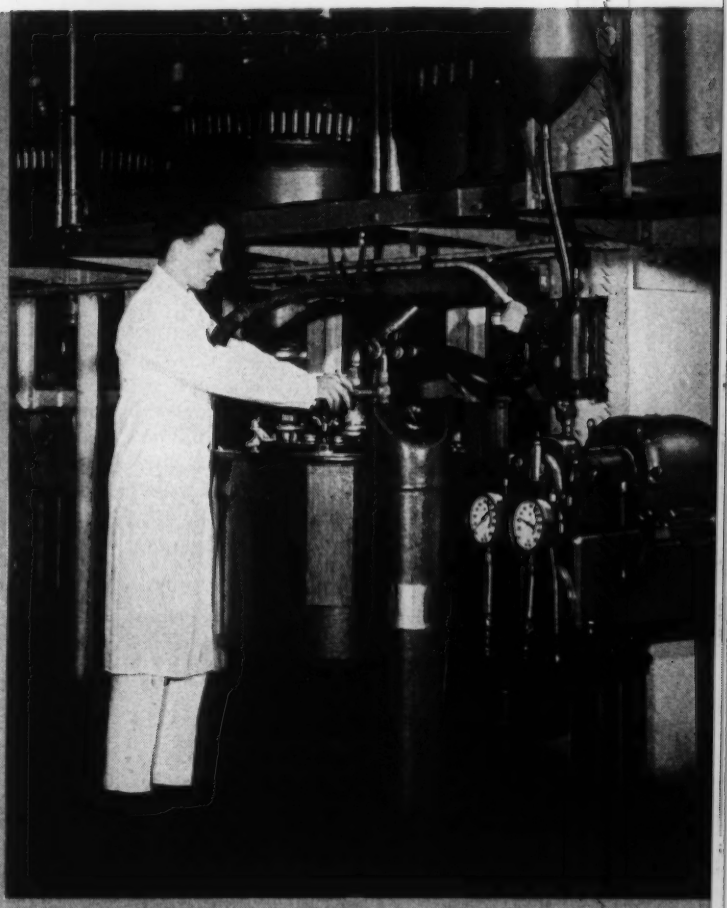
A cooling breeze might be welcomed in these hot summer months. How you can get one from a centrifugal or axial fan system is the subject of Kenneth Merz's article on air-circuit design. The article, incidentally, provides a very refreshing theme for artist George Farnsworth's front cover.

Facing Page—ITEM 507→

Any speed for you too!

Unique Oilgear Fluid Power "ANY-SPEED" Drives establish new production and economy records

Any desired speed from zero to maximum . . . any rate of acceleration . . . any rate of deceleration . . . any rate of hydrodynamic braking . . . any speed adjustment between operations . . . synchronization of two or more drives . . . direct or remote precision speed control irrespective of load, input power or oil viscosity changes . . . all with Oilgear Fluid Power "Any-Speed" Drives. Old and new users name them *"the drives"* for their heavy-duty needs. You probably didn't know this! Every day, people are equally surprised—*and far more amazed when they know the facts.* Write and get them *now*. THE OILGEAR COMPANY, 1568 W. Pierce Street, Milwaukee 4, Wisconsin.

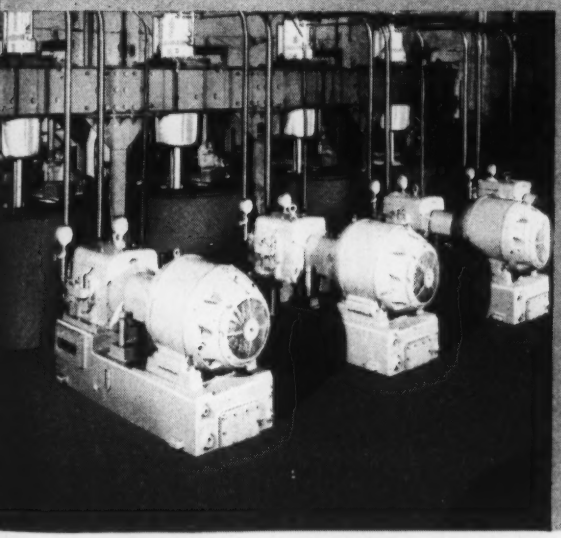


This Centrifuge at Abbott Laboratories

Leading house in pharmaceutical, drug and chemical field, Abbott Laboratories installed first Oilgear Drive on Tolhurst centrifuge in production department. Experience was so satisfactory it led to the inclusion of another Oilgear equipped Tolhurst centrifuge in their experimental laboratories.

SPECIFICATIONS: Speed continuously variable from zero to 1200 rpm max. (in this case). Full control of acceleration/deceleration speed and rate. Permits that infinitely modifiable speed best suited to loading, washing, spinning and unloading.

Photo Courtesy, Chemical Processing Magazine



This Centrifuge at powder plant in east

In a somewhat different application, these 4 Oilgear 60 hp "Any-Speed" Drives serve Tolhurst centrifuges in powder plant in the east. Centrifuge accelerates to 300 rpm for loading, to 900 rpm for 15-minute centrifuging, then decelerates to 70 rpm for "plowing." Unloading is automatic.

Tolhurst is a division of American Machine & Metals, Inc.

OILGEAR
Fluid Power

PIONEERS . . . NOW THREE PLANTS FOR FLUID POWE

PUMPS, MOTORS, TRANSMISSIONS, CYLINDERS AND VALVES

JET AIRLINER INTERIOR is duplicated exactly in this mockup of the cabin of a Boeing 707 Stratoliner. The half-million dollar, full-scale model is complete with air conditioning, running water, galley equipment, lighting system—all the features that will be built into the actual planes. The Stratoliner cabin is 98 ft, 8 in. long and 11 ft, 7 in. wide. Innovations are passenger service units above each row of seats—equipped with individual air inlets, reading lights, and emergency oxygen outlets—and removable plastic or plastic-laminated panels covering walls and ceiling. Planes are scheduled to be in service in 1959.

⅛-in. wall thickness. Lengths of glass rovings are formed into a loose yarn, without twist, which is then doubled back to make a U-shaped bundle. This bundle is placed in a trough partly filled with liquid resin and is immersed until thoroughly soaked. A steel wire is threaded through the tubing, attached to the bend in the U-shaped bundle, and used to pull the bundle through the tubing.

When the tubing is completely filled, the ends of the tubing are sealed with hose clamps. The tubing is wound on a mandrel and the assembly is placed in an oven for curing. Post curing is performed as required, and the springs are cut and ground to finished length.

Best results were obtained with an epoxy resin cured with m-phenylenediamine. These springs have torsional moduli of rigidity of the order of 1.0×10^6 psi. In 2-in. lengths they deflect ½-in. under a static load of 25 lb. Springs of this type, 3 in. long, retain 40 per cent of their original energy when compressed to their solid length and stored at 135 F for 13 days.

NEW LIGHT for emergencies and outdoor sports is this lantern developed by Burgess Battery Co. Lantern head with 2½-in. chimney fits over pack containing two 6-v batteries. Two screw caps hold the assembly without other wires or spring contacts. Simple circuit is built into lantern head base.

Mechanical and thermal properties of the plastic springs can be varied widely by proper choice of materials and dimensions. Stiffer and probably more brittle springs result when the glass content is increased.

Topics

Seventy million automobiles will be owned by Americans by 1965, estimates a Chrysler executive. Then, 8 or 9 million cars a year will be required by the U. S. population.

• • •

Economical operation of jet planes for short distances is made possible by recent advances in design, according to a Douglas engineer. The use of jets for distances as short as 225 to 335 miles is claimed more economical than use of piston-powered planes.

• • •

Largest wine vessel, a 530-ft tanker, is being built to carry 2,500,000 gal of the liquid from California to the East Coast in one trip. The ship will be equipped with stainless-steel tanks to transport the wine.

• • •

More comfortable casts for broken bones have been made of glass fiber. Such casts weigh about one-third as much as the plaster kind, can be altered in size if the patient loses or gains weight, and are removable for cleaning.

• • •

Keels for two atomic submarines were laid recently, making a total of nine nuclear-powered U. S. subs built or under construction. Six additional vessels are scheduled to be built during the next year.

• • •

Potential engineers are possibly being lost to other careers because of U. S. high schools' curricula. About half the schools do not offer courses in chemistry or physics. Only 11 per cent of students take courses in geometry.

• • •

Application of welding as a design and fabricating tool is the subject of a course of study offered engineering personnel by Baldwin-Lima-Hamilton Corp.

• • •

TV pictures from jet aircraft flying at supersonic speed are transmitted to the ground by a system developed by Philco. The system's performance at high speed and at altitudes above the reach of antiaircraft fire make it useful for military reconnaissance work. The picture is as good as or better than commercial television, according to Philco.

Facing Page—ITEM 508→

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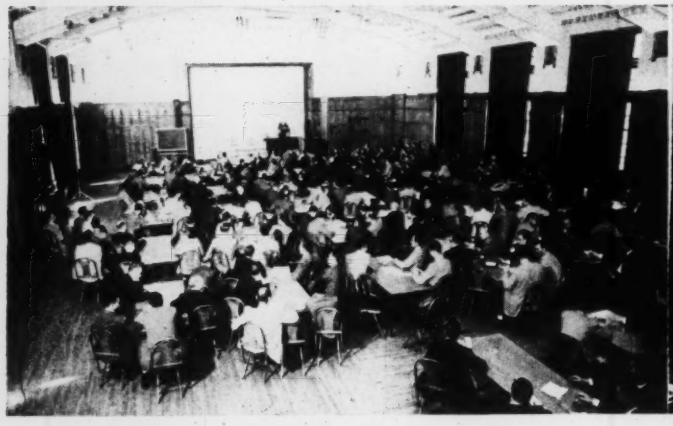
Third Mechanisms Conference at Purdue in May Drew 250 Engineers



General session at the Third Mechanisms Conference was one of three which treated kinematic synthesis, intermittent-motion mechanisms and cam design.

Group discussions gave engineers the chance to exchange ideas in their immediate interest. This was the machine tools and metalworking group.

Conference members included this group: C. N. Nekluton, V. P. Engineering, Universal Match Corp.; Joseph J. Reiss, chief applications engineer, Ferguson Machine & Tool Co.; D. V. Strock, special project engineer, and Jos. P. Wadleck, development & research engineer, both Aetna Standard Engr. Co.

Three of eleven in the planning committee were E. S. Ault, professor of machine design, Purdue; Colin Carmichael, editor, *Machine Design;* C. G. Bigelow, technical director, eneral Engineering Laboratories, AMF. Committee cochairmen were A. S. Hall Jr., Purdue, and B. L. Hummel, *Machine Design.*

Two pairs in the conference deck were Walter Diehl, Kidde Mfg. Co.; Simmon Tamny, Miehle Printing Press & Mfg. Co.; Albert A. Hess, also of Miehle; and A. Eugene Zabriskie, also of Kidde.

Luncheon in the Memorial Union Bldg. at Purdue was followed by discussion groups. A banquet the evening before was followed by observations on Europeon developments by R. S. Hartenberg, Northwestern Univ.

What is YOUR Control Problem?

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Control for every ac application

Allis-Chalmers offers an extensive line of manual and magnetic control to meet every condition of motor operation. Control functions, varying with specific job requirements, include full or reduced voltage starting, acceleration, speed control, reversing or non-reversing, and dynamic braking.

Custom protection

Built into all Allis-Chalmers control is the type and degree of protection dictated by the application. Controls are available in general purpose and special cabinet, including water-tight, dust-tight and explosion-proof enclosures. A-4516

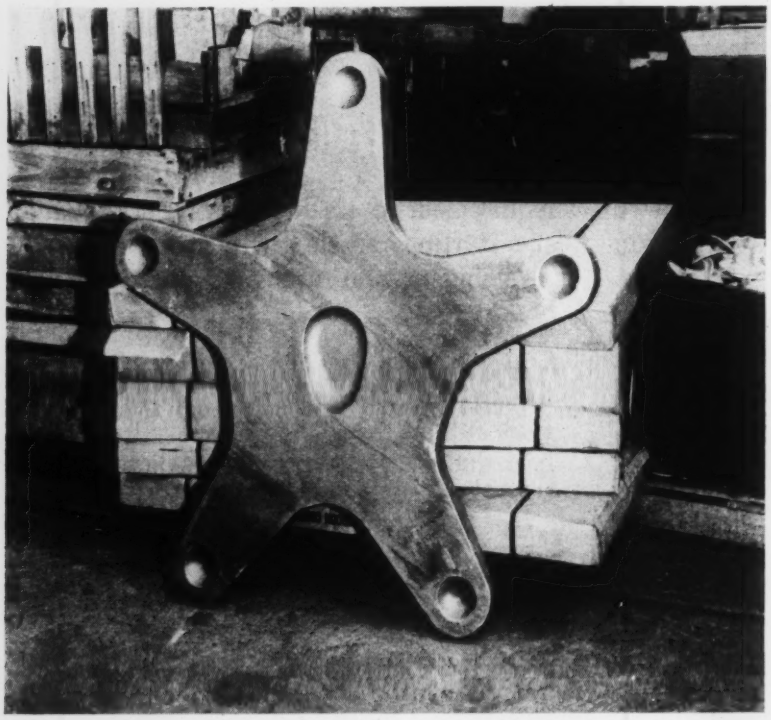
For complete information on any specific control problem, call your nearby Allis-Chalmers representative or write Allis-Chalmers, Milwaukee 1, Wis.

ALLIS-CHALMERS

A-C ALLIS-CHALMERS

—ITEM 509—

HUGE TIRES SERVE AS SNOWSHOES for a LeTourneau freight carrier designed for use above the Arctic Circle. The Sno-Train can operate at −65F and rides easily on top of 3 ft of snow on its 10-ft diam, 4-ft wide tires. All of the freight carrying trailers, as well as the engine car, have all-wheel drive. An electric motor in the center of each wheel provides driving power. A transparent bubble in the roof of the control car facilitates navigation by the stars and observation of the terrain of Arctic wastelands. Built for the Army Transportation Corps, the train can carry approximately 100,000 lb of supplies on its three flat-bed trailers.



LARGEST MAGNESIUM DIE FORGINGS are being produced in quantity on an 18,000-ton press at the North Grafton plant of Wyman-Gordon Co. The forging is a five-pointed plate more than 4½ ft in diameter and weighing 235 lb in rough form. After machining, the plates become part of the rotorhead in the Sikorsky S-56 helicopter.

Casting Process Uses Expendable Plastic Core

MYSTIC, CONN.—A technique called Cavityless Casting Process uses expanded polystyrene materials as an expendable pattern and is particularly useful for low-quantity and one-time production. All types of metals, ferrous and non-ferrous, have been cast successfully.

The plastic core is made in one piece or several pieces glued together. This formed piece is then placed in a sand mold and gates, risers and venting are added. With the plastic still in the sand, the metal is poured into the mold. The hot metal burns out the plastic and replaces it to form the casting.

The steps in Cavityless molding are like those in one-piece pattern molding, but in the former the pattern is left in the mold and more venting is required to support combustion of the plastic.

A technical paper contest has been announced by the Standards Engineers Society in connection

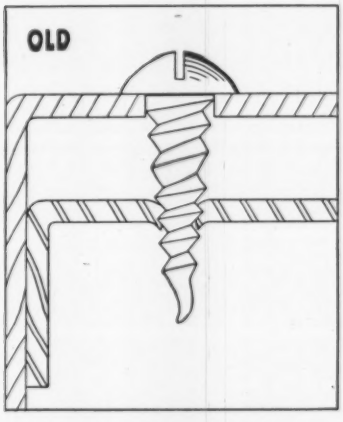
B.F. Goodrich Rivnut

provides shockproof nutplate, saves time and money

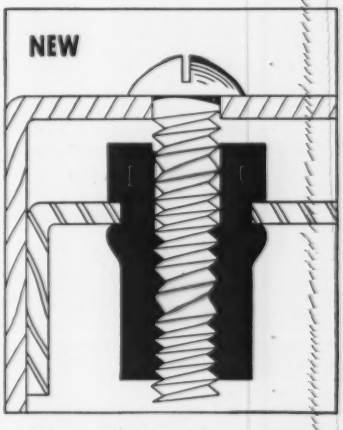
B. F. Goodrich Rivnuts provide accurate, shockproof nutplates in one, quick operation. They eliminate nuts, welding, tapping, clinching. They are particularly suited for blind applications where other methods of fastening are impossible. They give a tight, dependable seal. And save man-hours, too, because one operator can install a Rivnut in seconds.

Just as BFG Rivnuts speeded up output and eliminated assembly and service problems for the Graef Storm Window Co. (SEE PICTURES AT RIGHT), Rivnuts are uniquely successful when used in any thin sheet metal. They are the only method of fastening available that gives 6 clean threads for attachment. They can even be installed *after* enameling.

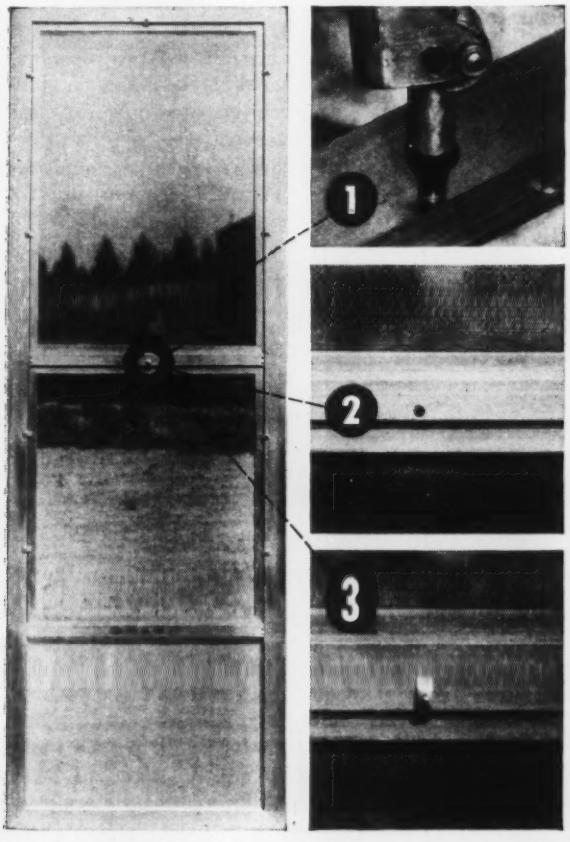
If you're looking for a fastener that can improve your product and cut production time, why not get the help of The B. F. Goodrich Co., Dept. MD-66, Akron, Ohio.



USING SELF-TAPPING SCREWS. To attach insert clips to aluminum storm doors, the Graef Storm Window Co. considered a conventional method, tried self-tapping metal screws. They found that due to the softness of the aluminum, screws pulled out and enlarged the hole. A new hole had to be made or a larger self-tapping screw used. They could foresee service problems. When storm windows were changed by the user, the metal would pull or tear.



USING B. F. GOODRICH RIVNUTS. No assembly problems, no service problems, reports Graef. Rivnuts speed assembly—installing in door stiles takes only seconds. They provide a firm, accurate nutplate that does not loosen with shock or vibration. At least 6 threads are clean for attachment, eliminating any pulling or tearing of metal during assembly or later, when storm windows are changed by the user.



HOW GRAEF SPEEDS ASSEMBLY USING RIVNUTS
(1) Rivnut is inserted in blind aluminum door stile. Heading tool forms bulge inside in one, quick operation. (2) Rivnut fits smoothly, tightly. Six clean threads provide attachment for (3) bolt and retaining clip which holds screen insert. Door slamming, change of inserts will not loosen the nutplate the Rivnut provides.

Send now for

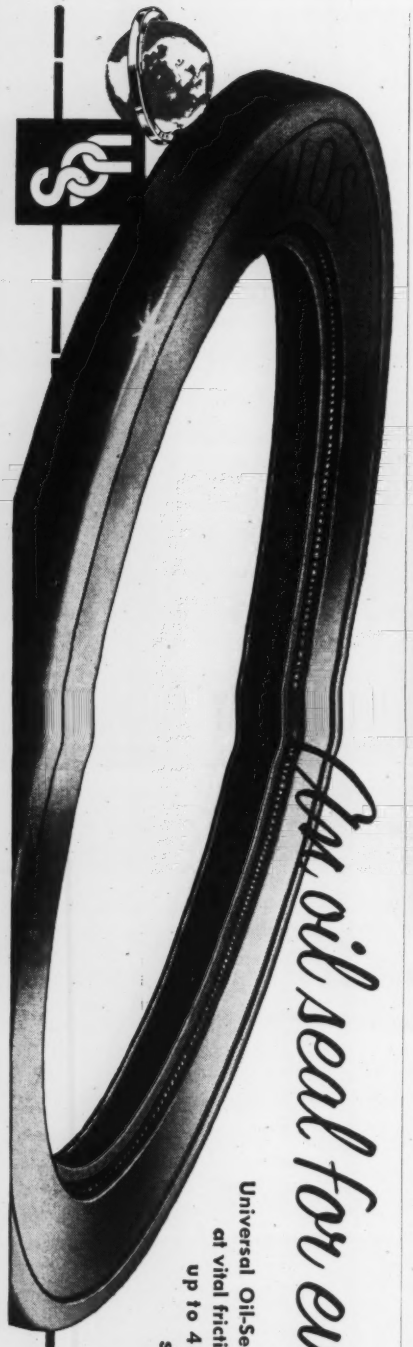
FREE RIVNUT

Demonstrator

Demonstrates with motion how you can use Rivnuts to fasten TO and fasten WITH. Explains construction, simplicity of installation. Get your free copy today by writing to: The B. F. Goodrich Company, Department MD-66, Akron, Ohio.

B.F. Goodrich RIVNUTS

The only one-piece blind rivet with threads



Low oil seal for every purpose!

Universal Oil-Seals are assembled units ready for installation at vital friction points. They are available in special designs up to 48" diameter shafts with optional leather, synthetic rubber or composition packings.

STANDARD SEALS CARRIED IN STOCK. WRITE FOR COMPLETE CATALOG.

—ITEM 511—

UNIVERSAL OIL SEAL CO.
PONTIAC 12, MICHIGAN

with its Fifth Annual Meeting to be held in Washington, D. C., Oct. 3, 4 and 5. The winning paper will be read at the meeting and published in *Standards Engineering*. Inquiries for further details should be addressed to the Society, P. O. Box 281, Camden 1, N. J.

Passengers Ride High in Santa Fe's New El Capitan

CHICAGO, ILL.—At public exhibitions in June the Santa Fe Railway will introduce a new El Capitan train for transcontinental service between Chicago and Los Angeles. Opposite from other trends in passenger equipment, the cars of this train will be oversize and extra heavy.

Built by the Budd Co., Philadelphia, the new cars are 15½ ft in height—2 ft higher than conventional equipment. Passengers will be seated on upper decks of the cars in reclining seats 8 ft above the rails, or 4 ft higher than the floor of a regular chair car.

Santa Fe claims that experiments since 1954 with two "Hi-Level" cars have proved this extra elevation provides a smoother ride with less noise and vibration. Public acceptance of the new equipment is said to be favorable.

Double-level arrangement of the "Hi-Level" cars eliminates vestibules and provides 28 more passenger seats than cars on the present El Capitan.

Doors are located at the center on both sides of the new cars. Center stairways lead to the seating deck. Lower levels of the chair cars are devoted to luggage shelves and rest rooms. Luggage is unloaded through separate openings in the sides of the cars.

Upper levels of dining cars will be devoted entirely to table space for 80 diners, with a completely electric kitchen located on the lower deck. All cars will be equipped with a public address system carrying recorded music, radio programs and train announcements.

Navy Contract Specifies Plastic for Whaleboats

WASHINGTON, D. C.—The Navy has recently awarded to Wizard Boats Inc. a contract for 26-ft motor whaleboats to be made of plastic.

The plastic boats are expected to be superior to the wooden types in several ways. Deterioration resulting from outdoor storage is practically eliminated, it is said,

and the plastic boats are resistant to decay fungus. It is also claimed that repairs are made easily.

Lower fuel consumption is of great importance in the design of future automobiles, according to Alfred L. Boegehold, manager of the General Motors Research Staff Facilities. Mr. Boegehold predicts increased use of lightweight metals, such as aluminum and magnesium, and more efficient engines as means to reduce fuel consumption. Size of cars will not be affected, he said.

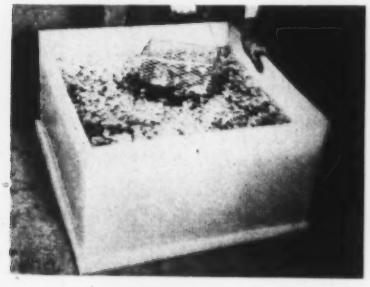
Plastic Pillows Retard

Evaporation from Tanks

CLEVELAND, O.—Designed to retard the evaporation of liquids in open tanks and vessels, little pillows made of polyethylene and filled

with air have been announced by American Agile Corp.

Essentially, the pillows are small floating tank covers. They allow



access into solutions without lifting or removal. A layer 1½ in. thick is considered effective.

Made of polyethylene, the pillows are chemically resistant to a large variety of industrial solutions. They may be used in conjunction with nickel and chrome solutions, solvents at room temperature, re-

(*Continued on Page 22*)

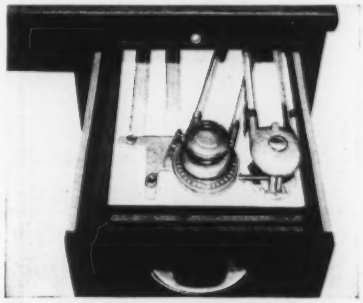
DRAFTING TRENDS

Chief Draftsman W. P. Nickels of Tennessee Gas Transmission Company (Houston, Texas) at work with his portable "Desk Topper"

Portable drafting unit sets up in two minutes

A handy drafting unit with the precision of a full-size drafting machine is now available to engineers who need portable facilities. Called "Desk Topper," the package-size unit can travel along with you or slip away in an office drawer. All essentials are included: drafting machine, set of scales, folding board, storage container for tools, and paper dispenser.

The "Desk Topper" sets up quickly (2 minutes) on any desk or table—at home, in the office, hotel room or studio.



The complete "Desk Topper" hides away quickly in any standard desk drawer or in the sturdy carrying carton. (Handsome luggage case is available at extra cost.)

The unit comes packed in a lightweight carrying carton for easy portability. For engineers who use the board only occasionally, the entire unit fits into any standard desk drawer.

Manufactured by Universal Drafting Machine Corp., "Desk Topper" has the professional features of their large "Boardmaster" machine—360° protractor, automatic 15° indexing, full line base selector, double 10′ vernier and clamp, elbow height adjustment, screw anchor, enclosed band and pulley arms, built-in brakes for 10° board slope.

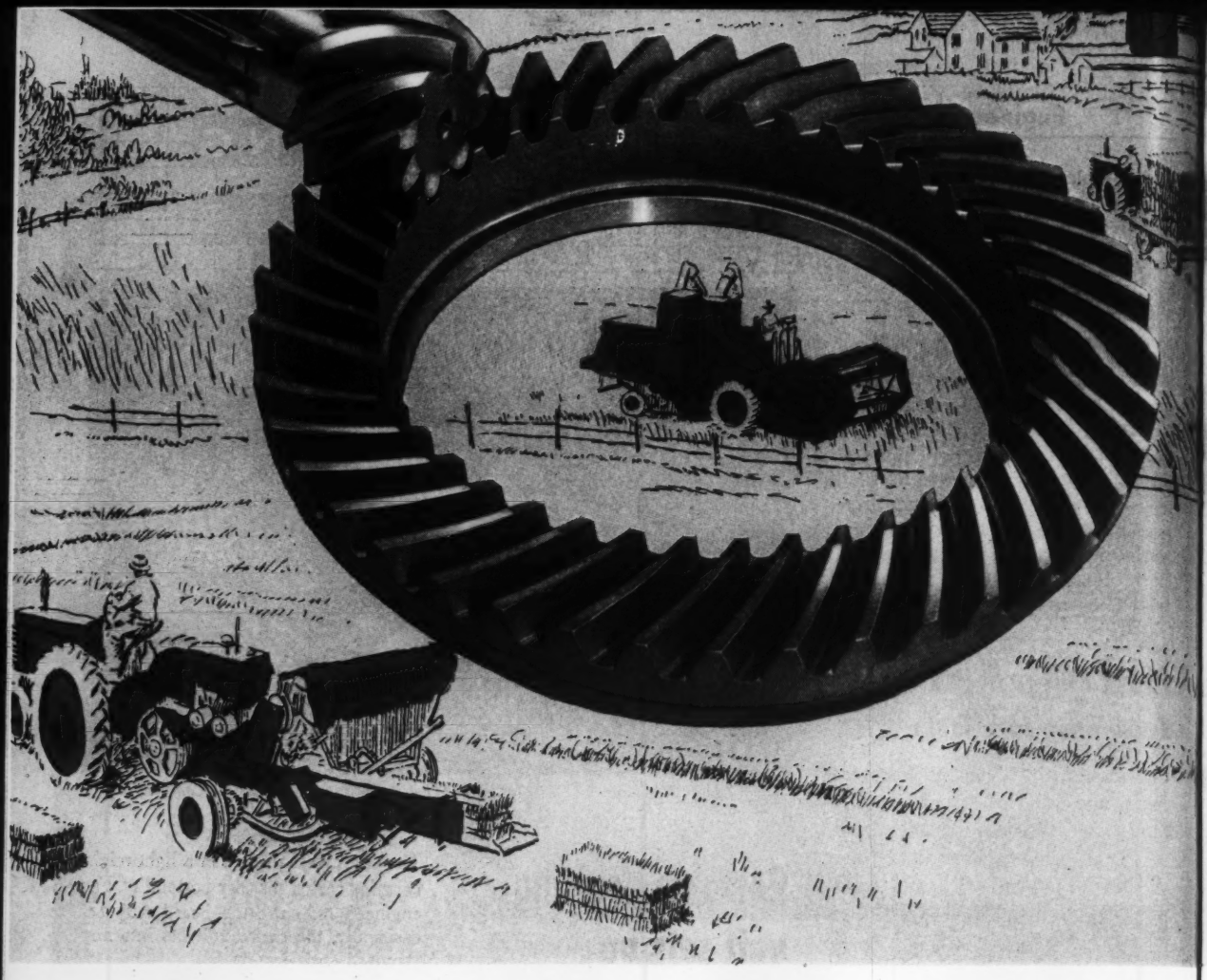
The smooth linoleum surface board measures 21″ x 23½″ when open, 21″ x 11¾″ when closed. Normal drawing capacity is 17″ x 22″, or 24″ x 36″ when mounted to a larger board. The legs with rubber feet fold up automatically, provide a 10° slope in use.

The "Desk Topper" scales are another excellent feature. Self-locking and self-aligning, they eliminate two common causes of drafting machine inaccuracy—loose chucking, and errors in right angle alignment.

Further information on "Desk Topper" is available from the Reader Service Division of the Frederick Post Company, 3652 N. Avondale Avenue, Chicago 18.

POST

SENSITIZED PAPERS & CLOTHS • TRACING & DRAWING MEDIUMS • DRAWING INSTRUMENTS & SLIDE RULES
ENGINEERING EQUIPMENT & DRAFTING SUPPLIES • FIELD EQUIPMENT & DRAFTING FURNITURE



AGRICULTURE-geared to modern production standards

Unlike industrial machinery, farm equipment is exposed to everything that nature can throw at it. Soil is the element in which farm machines work. They're exposed to every fury in the book—heat, cold, snow, ice, dust. They stand idle much of the time, then go to work at an instant's notice, performing perfectly for hundreds of gruelling hours. And they must be built against breakdown that interferes with the critical time schedules of much farm work.

That gears of our manufacture are specified for so many different kinds and makes of farm machinery is proof of their rugged ability to perform reliably under the most rigorous circumstances. Their daily work on America's farms proves their fitness for service in your products or equipment.

Why not write today for further information?

DOUBLE DIAMOND TRADE MARK GEARS

FOR AUTOMOTIVE, FARM EQUIPMENT AND GENERAL INDUSTRIAL APPLICATIONS
GEAR-MAKERS TO LEADING MANUFACTURERS

Automotive Gear Works, inc.

ESTABLISHED IN 1914 RICHMOND, INDIANA

SUBSIDIARY OF EATON MANUFACTURING COMPANY

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USE A YELLOW CARD *for More Information . . .*

CIRCLE ITEM NUMBERS—Throughout the magazine, each advertisement carries an Item Number for use in requesting further information. All product descriptions, announcements and Helpful Literature items are also numbered, and for greater convenience are indexed below by Item Numbers.

EDITORIAL CLIPSHEETS—So you won't have to "clip" this issue, we'll be glad to send a personal copy of any article as long as the supply lasts. Just fill in the page number and title of article in the place provided on the Yellow Card.

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413	438	463	488	513	538	563	588	613	638	663	688	713	738	763
414	439	464	489	514	539	564	589	614	639	664	689	714	739	764
415	440	465	490	515	540	565	590	615	640	665	690	715	740	765
416	441	466	491	516	541	566	591	616	641	666	691	716	741	766
417	442	467	492	517	542	567	592	617	642	667	692	717	742	767
418	443	468	493	518	543	568	593	618	643	668	693	718	743	768
419	444	469	494	519	544	569	594	619	644	669	694	719	744	769
420	445	470	495	520	545	570	595	620	645	670	695	720	745	770
421	446	471	496	521	546	571	596	621	646	671	696	721	746	771
422	447	472	497	522	547	572	597	622	647	672	697	722	747	772
423	448	473	498	523	548	573	598	623	648	673	698	723	748	773
424	449	474	499	524	549	574	599	624	649	674	699	724	749	774
425	450	475	500	525	550	575	600	625	650	675	700	725	750	775

SEND COPIES OF FOLLOWING ARTICLES IN THIS ISSUE

Page No. Title of Article

....

....

....

....

Please print plainly

NAME _____

TITLE _____

COMPANY _____

PRODUCT MANUFACTURED _____

ADDRESS _____

CITY _____ ZONE _____

STATE _____

Do not use this card after Aug. 28, 1956

FIRST CLASS
Permit No. 36
CLEVELAND, OHIO

BUSINESS REPLY CARD
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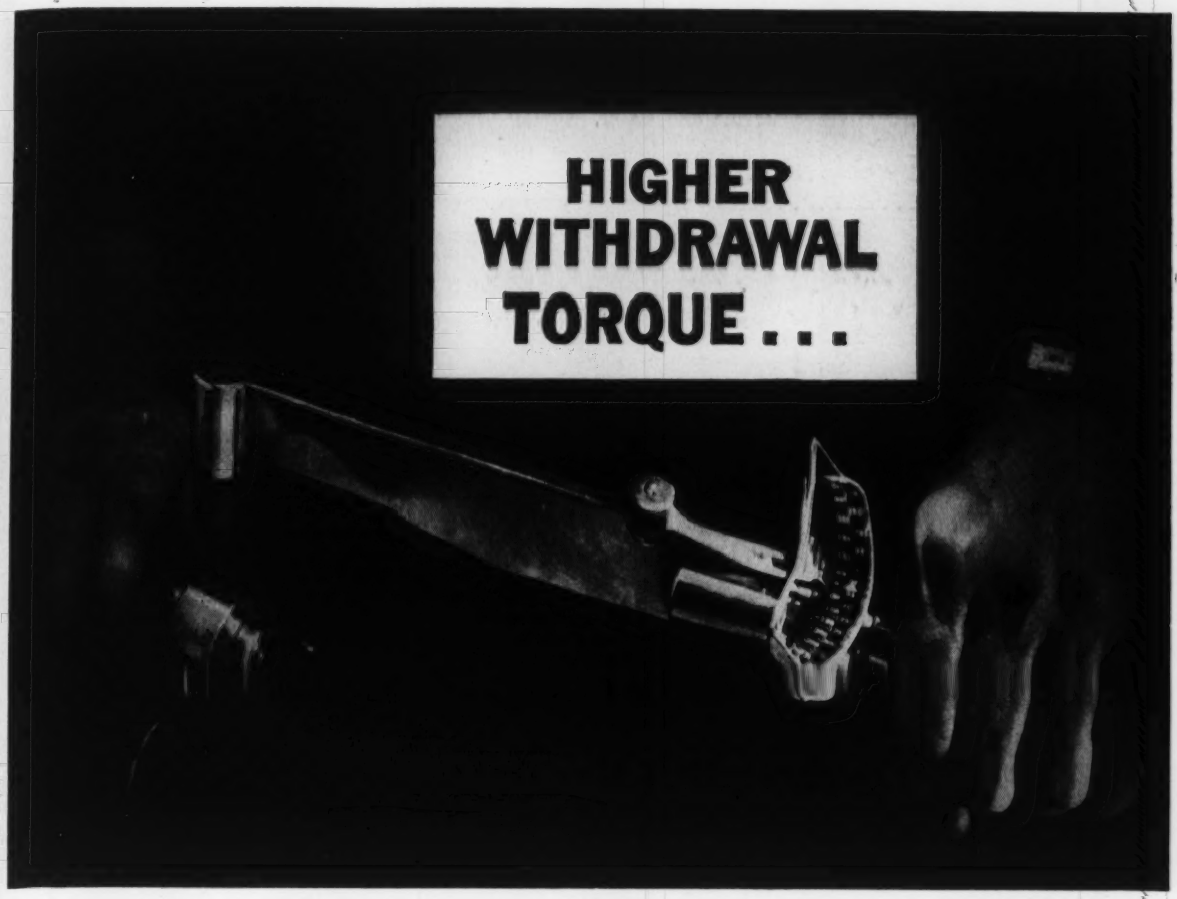
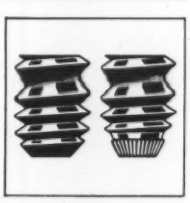


Greater resistance to removal holds Allenpoints tighter in your products

Tests prove that ALLENPOINT Set Screws have HIGHER WITHDRAWAL TORQUE than serrated point set screws

HIGHER WITHDRAWAL TORQUE WITH ALLENPOINTS! In ¼" x ¼" sizes, tightened to shear point of key, Allenpoints required 75 inch-pounds removal torque. Serrated point set screws gave up their hold at only 50 inch-pounds removal torque.



ONE MORE FULL THREAD WITH ALLENPOINTS! Compare, and you'll find that Allenpoints have *one more full thread* than same size serrated point set screws. That means greater holding power, especially in the much-used "square" sizes.

CLEANER, MORE UNIFORM SOCKETS WITH ALLENPOINTS! Allenpoint sockets are *"pressur-formd"* to preserve the long fibers of the steel uncut throughout the *entire* length of the screw. This makes a deep socket of maximum strength and accuracy, in which the key seats with great exactness.

Specify ALLENPOINTS for far greater *holding* power — the kind of fastenings that "stay put". Genuine Allenpoints and other Allen fasteners are available from your Industrial Distributor — standard items immediately, special items very promptly. Write for full information.

You want maximum holding power from every set screw in your product. Here's why you'll get that from ALLENPOINT ○ Set Screws: Allenpoints and serrated point set screws were recently compared in laboratory tests. They were the kind of tests you'd make in your own plant — random samples of each were chosen from regular stock boxes from distributors' shelves.

In each test, keys were tightened right up to the shear point — maximum tightening point for any set screw. HIGHER WITHDRAWAL TORQUE was required to release the ALLENPOINT ○ Set Screws.

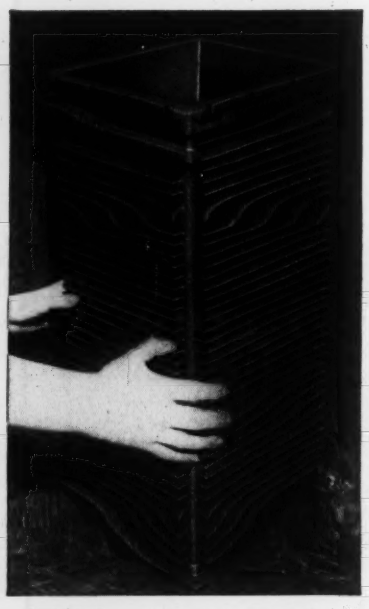
Translated into your own product, this means more dependable fastening with ALLENPOINTS.

—ITEM 514—

(*Continued from Page* 15)

agents and water.

Average density of the pillows is less than 9 lb per cu ft. They measure ⅝-in. OD by 1¼ by ¼-in. Wall thickness is 0.015-in.



Welded pressurized housing for airborne electronic equipment

Strong, sound, lightweight welded assemblies

Magnesium is easy to weld by the inert gas shielded arc method.

Welded joint strengths are high; using AZ31 alloy sheet, the joint strengths average 86% of the **parent metal with all weld bead** ground off smooth. If a bead is left, strengths can equal or exceed the parent metal strength.

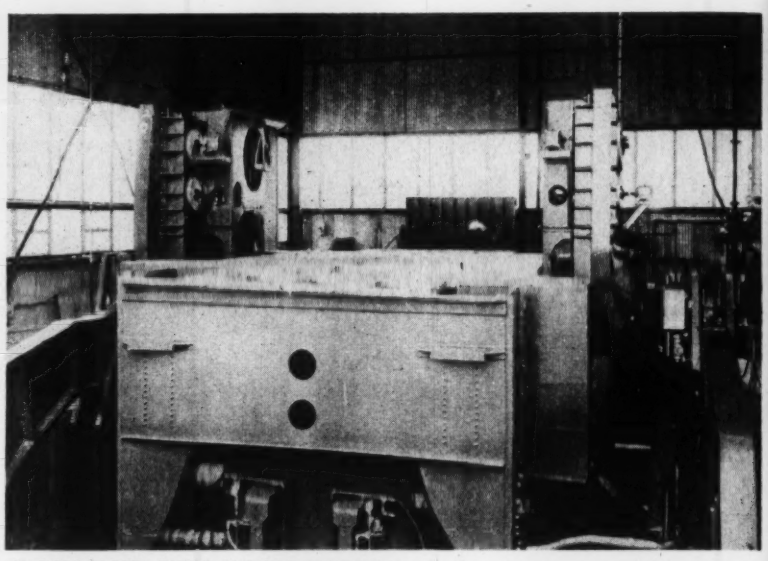
Magnesium welds are not subject to microporosity so common with many metals. The average magnesium weld is sound and pressure-tight. Where the designer must enclose his electronic equipment in a pressurized heat exchanger, magnesium is his most satisfactory material . . . and the added bonus is light weight.

B&P engineers will help you redesign in magnesium. B&P offers the magnesium industry's most complete facilities for fabrication and assembly. Your inquiry will bring answers to problems of magnesium welding: this 12-page booklet.

BROOKS & PERKINS, INC.

1940 West Fort Street
Detroit 16, Mich.

—ITEM 515—



SLOSH AND VIBRATION TABLE at Boeing Airplane Co. tests aircraft fuel cells and tanks. Said to be the world's largest vibration machine, it contains eight 46,000 lb force output vibration exciters, has a platform area 12 by 20 ft, and can vibrate a 50,000 lb specimen and fixture in two directions while at the same time "sloshing" them through a 30-degree angle.

Meetings AND EXPOSITIONS

Aug. 6-8—

Society of Automotive Engineers Inc. National West Coast Meeting to be held at the Mark Hopkins Hotel, San Francisco. Additional information can be obtained from society headquarters, 29 W. 39th St., New York 18, N. Y.

Aug. 21-24—

Western Electronic Show and Convention. Show headquarters, Pan Pacific Auditorium; Convention headquarters, the Ambassador Hotel, Los Angeles. Cosponsored by the West Coast Electronic Manufacturers' Association and the Los Angeles and San Francisco sections representing the Seventh Region of the Institute of Radio Engineers. Additional information can be obtained from Wescon, 344 N. La Brea Ave., Los Angeles 36, Calif.

Sept. 7-9—

Metal Powder Association. Fall Meeting to be held at the Homestead, Hot Springs, Va. Additional information can be obtained from association headquarters, 420 Lexington Ave., New York 17, N. Y.

Sept. 10-12—

American Society of Mechanical Engineers. Fall Meeting to be held at the Cosmopolitan Hotel, Denver. Further information can be obtained from society headquarters, 29 W. 39th St., New York 18, N. Y.

Sept. 10-13—

Society of Automotive Engineers. National Tractor Meeting and Production Forum to be held at Hotel Schroeder, Milwaukee. Additional information can be obtained from society headquarters, 29 W. 39th St., New York 18, N. Y.

Sept. 11-13—

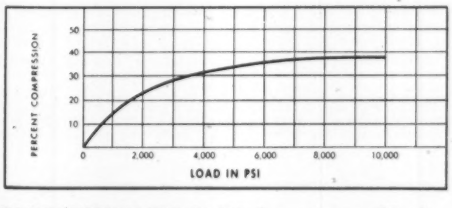
American Die Casting Institute. Annual Meeting to be held at the Edgewater Beach Hotel, Chicago. Further information can be obtained from the institute, 366 Madison Ave., New York 17, N. Y.

New heavy-duty fiber gasket seals at up to 250° F.

Combinations of heat and pressure that cause ordinary plant fiber gaskets to fail are handled successfully by Armstrong Accopac® N-820—a dense new material made by a patented Armstrong process. It requires a minimum flange load of 2,000 psi and seals at temperatures up to 250° F.

The special latex binder in N-820 will not leach out in alternately wet-and-dry applications. Shrinkage due to binder loss is eliminated because N-820's binder is non-volatile and non-extractable. It stays in.

N-820 conforms well to flange surfaces, yet permits minimum torque loss. It is already being used successfully on a wide range of heavy-duty applications, often as an economical replacement for asbestos sheet packing where temperatures do not exceed 250° F. For data sheet and samples, write to Armstrong Cork Co., 7006 Dean St., Lancaster, Penna.



COMPRESSIBILITY. N-820, less compressible than other Accopac materials, is recommended for heavy-duty applications where minimum flange pressures will be 2,000 psi and where temperatures will not exceed 250° F.

Armstrong ACCOPAC

. . . used wherever performance counts

Why Offer Less Than CHEMLON* Packings In Your Hydraulic Cylinders...

Hydraulic equipment manufacturers are now taking a *second* look at the many advantages of "John Crane" CHEMLON hydraulic packings and offering them in place of leather, fabric-reinforced and similar packings.

THE REASON . . . CHEMLON provides several very important service advantages.

1. Increased cylinder life due to the inherent non-frictional qualities of CHEMLON.
2. Longer packing service life—CHEMLON outlasts all other types of packing to a remarkable degree . . . decidedly cuts replacement, down time and maintenance.
3. Universal application—CHEMLON'S inertness to all types of hydraulic fluids, including non-flammables and synthetics . . . eliminates the need for customers stocking a wide range of special packings.
4. Trouble-free performance—CHEMLON withstands temperature conditions encountered in hydraulic service up to 350°F.

"John Crane" CHEMLON–*The Best in Teflon*–offers a complete line of piston cup, "U" cup and flange packing for every service requirement.

Get the new bulletin No. P-322 on "John Crane" Hydraulic Packings.

Crane Packing Co., 6425 Oakton St., Morton Grove, Ill. (Chicago Suburb). *In Canada: Crane Packing Co., Ltd., Hamilton, Ont.*

*"John Crane" fabricated from DuPont Teflon

John Crane

MECHANICAL PACKINGS

SHAFT SEALS

TEFLON PRODUCTS

LAPPING MACHINES

THREAD COMPOUNDS

CRANE PACKING COMPANY

MEN

OF MACHINES

Formerly chief project engineer, **William J. Adams Jr.** has been appointed assistant manager of the central engineering department of Food Machinery and Chemical Corp., San Jose, Calif. Mr. Adams was chief engineer of the company's Bolens Products Div. Previously, he was associated with General Electric Co. as an engineer.

R. A. Millermaster recently was appointed vice president in charge of development by Cutler-Hammer Inc., Milwaukee. He joined the company as test engineer in 1927 and has been manager of development since 1952.

Vernon H. Vogel has been appointed director of engineering of the Aeronautical Div. of Robertshaw-Fulton Controls Co., Greensburg, Pa.

Wagner Electric Corp., St. Louis, has consolidated its electrical and automotive engineering and research facilities under the direction of **P. C. Ford,** newly appointed executive engineer. Mr. Ford was formerly chief engineer of the Elec-

P. C. Ford

trical Div. **C. E. Widell** has been named director of research and development. He had been on special assignment with the engineering and research departments. **P. J. Reese,** formerly manager of development and application engineering of the Automotive Div., was made assistant director of research and development. In the Electrical Div. **H. B. Keath** and **A. E. Frohardt** were named chief product engineers for transformers and motors respectively. **E. E. Wallace** was named chief product engineer for automotive and industrial brake products. **W. R. Freeman,** who was chief automotive engineer, has been made consulting engineer on automotive product design and research and development.

Northrop Aircraft Inc., Hawthorne, Calif., recently announced the promotion of three members of its engineering division. **George Mangurian,** formerly chief of structures, has been named chief analytical engineer; **Roy P. Jackson** has been made assistant chief engineer; and **Don D. Warner** has been appointed chief of structures.

Gordon W. Smithson has been named vice president and chief engineer of Potter & Johnston Co., Pawtucket, R. I. Mr. Smithson joined the company in 1936 and has been chief engineer since 1953.

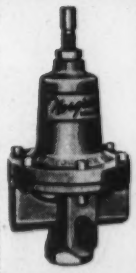
Gordon W. Smithson

Norgren CONTROL VALVES

for Accurate Control of Air, Water, Oil, and Other Fluids

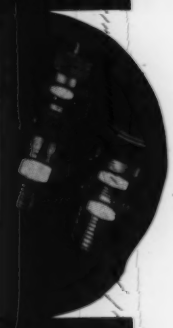
RELIEF VALVES

Diaphragm Type Valves Automatically protect fluid lines and connected equipment from damage resulting from pressure build-up. ⅛" to 1" pipe sizes.



Pop Safety Valves Prevent build-up of dangerous, excessive pressures on air tanks. ⅛" to ½" sizes.

Low Flow Relief Valves Small, inexpensive, valves for relief at low rates of flow. ⅛" and ¼" sizes.

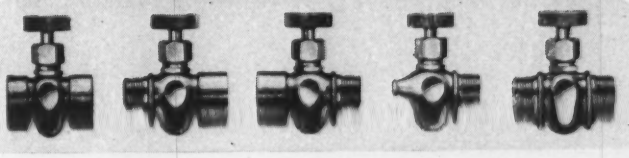


FLOW CONTROL VALVES

For accurate control of air and hydraulic cylinders. Two-way valves provide controlled flow in both directions; single-way valves provide regulated flow in one direction with full flow in the opposite direction. Also for flow control by means of adjustable metering on fluid lines. For pressures up to 250 psi on air and hydraulic systems; for pressures up to 125 psi on steam and hot water systems. ¼", ⅜", ½" pipe sizes.

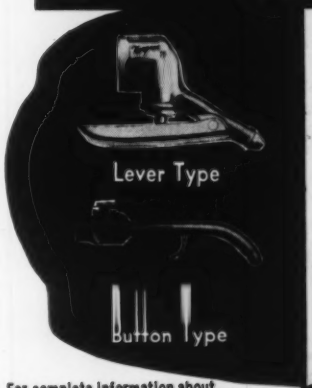
Two-Way Valve

NEEDLE VALVES AND COCKS



For controlling the flow of air, liquids and gases. For pressures up to 250 psi. Machined from brass bar stock. Leakproof. Double female, male and female, double male, male and male cock.

BLOW GUNS



For controlling the direction and flow of compressed air for removal of dust, lint, wood or metal chips, water and other foreign materials from parts in production and from machinery. ¼" and ⅜".

For complete information about Norgren Control Valves, call your nearby Norgren Representative listed in your telephone directory—

Norgren CO

or WRITE THE FACTORY FOR NEW No. 700 CATALOG
3442 So. Elati St., Englewood, Colo.

Wherever Air is Used in Industry

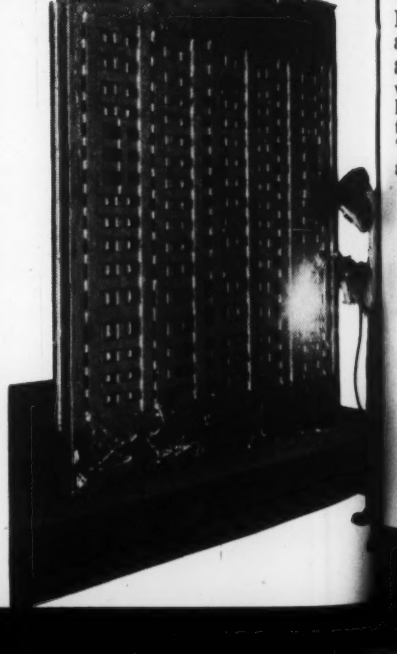
HOW USS "T-1" STEEL IMPROVES THESE PRODUCTS...

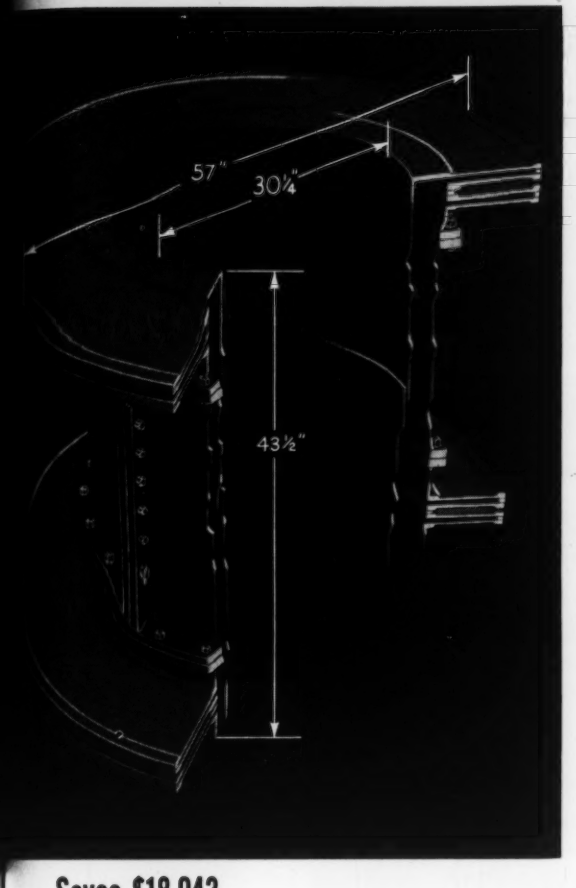
... Lops off 1,047 Pounds

Trays for ore clean-up buckets need tremendous resistance to impact, abuse and abrasion. Blaw-Knox Company, Pittsburgh, Pa., found that they weigh half a ton less, and cost less to fabricate when made from USS "T-1" Steel plate instead of heavy steel castings.

... 534 Easier Welds

This printing press bedplate, manufactured by Graver Tank & Manufacturing Co., Inc., must be welded in 534 places. High alloy steel with the needed strength was very difficult to weld. But USS "T-1" Steel is easy to weld . . . and has the needed strength to keep these bedplates, used on high-speed printing presses, as lightweight as possible.





... Saves $18,043

In structures like this, which are steel bellows that flex up-and-down and sideways, large thermal expansions can be accommodated. These expansion bellows surround struts which support a large axial flow compressor rotor. The bellows are connected from the compressor stator to the foundation. Westinghouse Electric Corporation switched to USS "T-1" Steel . . . promptly cut not only the cost of machining and welding, but also cost of the steel itself—saved $18,043.

... Three Ways Better

International Nickel Company of Canada expects USS "T-1" Steel to increase the service life, to reduce the maintenance, and lower the long-term cost of ore cars like this one; because "T-1" Steel has far greater strength, toughness, and resistance to abrasion than steel used previously. The car builder, Canadian Car and Foundry Co., Ltd., has had no difficulty fabricating this very strong alloy steel.

HOW USS "T-1" STEEL CAN HELP YOU

The great strength and toughness of USS "T-1" Steel (90,000 psi. minimum yield strength) helps you to increase the capacity and durability of power shovel buckets and storage tanks without increasing weight.

Its excellent weldability enables you to fabricate large equipment out in the field without heat treatment . . . thus, reduces fabricating and shipping costs and speeds up construction.

Its unusual toughness at sub-zero temperatures helps you to lengthen service life of equipment that must take impact, abrasion, and abuse in all weather.

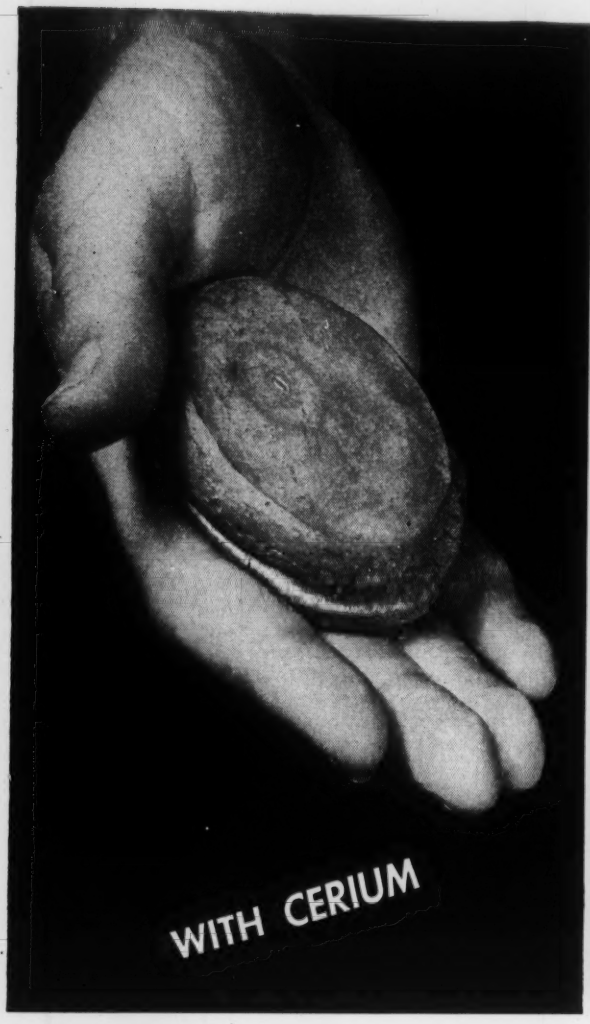
USS "T-1" Steel also gives you good creep rupture strength to 900° F. It often can be substituted for more expensive steels that are more difficult to fabricate. There is a place for "T-1" Steel somewhere in your designs. Write, wire, or phone for more information. United States Steel, Room 5387, Pittsburgh 30, Pa.

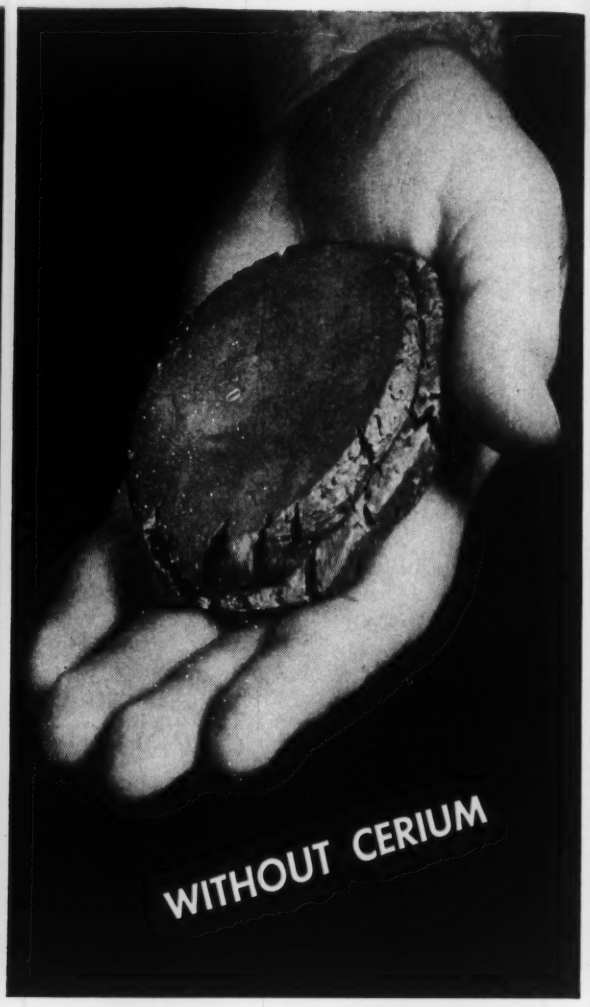
UNITED STATES STEEL CORPORATION, PITTSBURGH · COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO · TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA.
UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS, COAST-TO-COAST · UNITED STATES STEEL EXPORT COMPANY, NEW YORK

USS "T1" CONSTRUCTIONAL ALLOY STEEL

USS

UNITED STATES STEEL





HOW Carpenter USES RARE EARTH ELEMENTS TO IMPROVE FORGEABILITY OF ALLOYS FOR ELEVATED TEMPERATURE SERVICE

The value of rare earth elements in certain alloys for elevated temperature service can be seen in this hot forgeability test. Cast cones, identical except for the addition of cerium in one, are heated to forging temperature and upset or hammered into flat "pancakes". Note the relative freedom from cracks and tears in the specimen containing cerium.

What does this improved hot workability mean to you? It means better forged finishes requiring less machine clean-up . . . less wasted steel . . . fewer rejects . . . faster fabricating.

Carpenter alloys for elevated temperature service have an enviable reputation for improved forgeability, and exceptional cleanness which meets the strictest inspection requirements.

Carpenter pioneering in tool steels, super corrosion resisting steels and free-machining stainless steels has helped hundreds of companies to improve products and cut costs. This same specialty mill experience can help you do a better, low cost job on any parts or products you make for high temperature service. It'll pay you to investigate. Contact your Carpenter Representative, or drop us a line on your company letterhead. *The Carpenter Steel Company, 120 W. Bern St., Reading, Pa.*

Specify Carpenter alloys for elevated temperature service and get these three big advantages . . .

Improved Forgeability
Greater Uniformity
Cleaner Steel

Carpenter STEEL

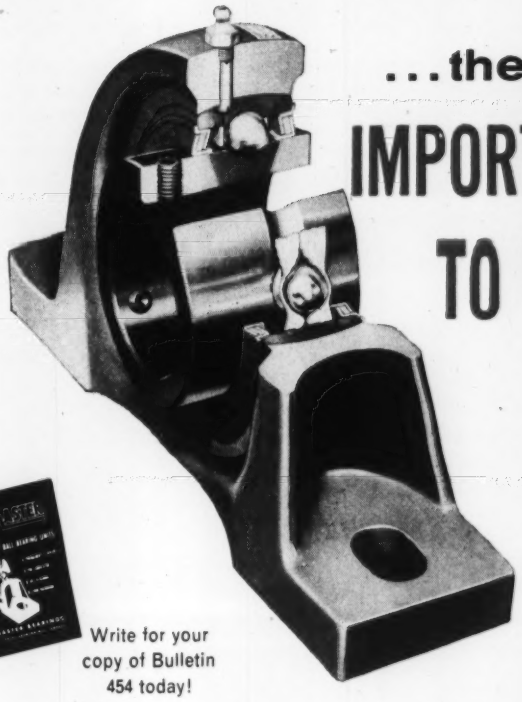
Improved Alloys for Elevated Temperature Service

—ITEM 520—
For More Information Circle Item Number on Yellow Card—page 19

This combination of features is EXCLUSIVE with . . .

SEALMASTER

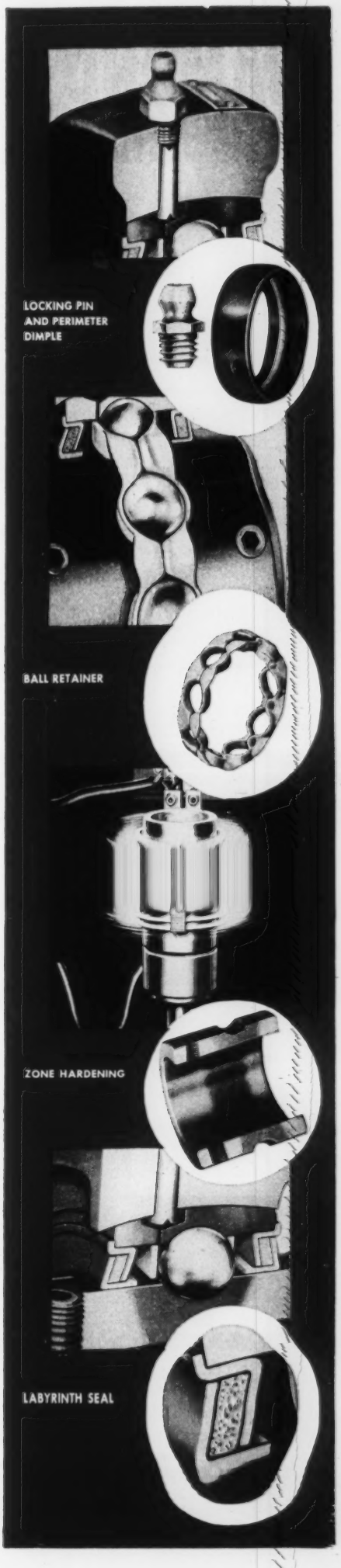
BALL BEARING UNITS



. . . they are

IMPORTANT TO YOU!

Write for your copy of Bulletin 454 today!



The products you design today to meet the demands of tomorrow must be carefully engineered right down to the smallest component. The product must be geared to the demands of an "automation minded" world and the competition of the years ahead. Production schedules can't be kept up when machinery is down for maintenance. No component you can build into your products will mean more to its efficient performance than the bearing units carrying the load. The exclusive combination of features found only in SEALMASTER self-aligning, pre-lubricated Bearing Units are important to your product's continuous performance and acceptance.

SEALMASTER BEARINGS

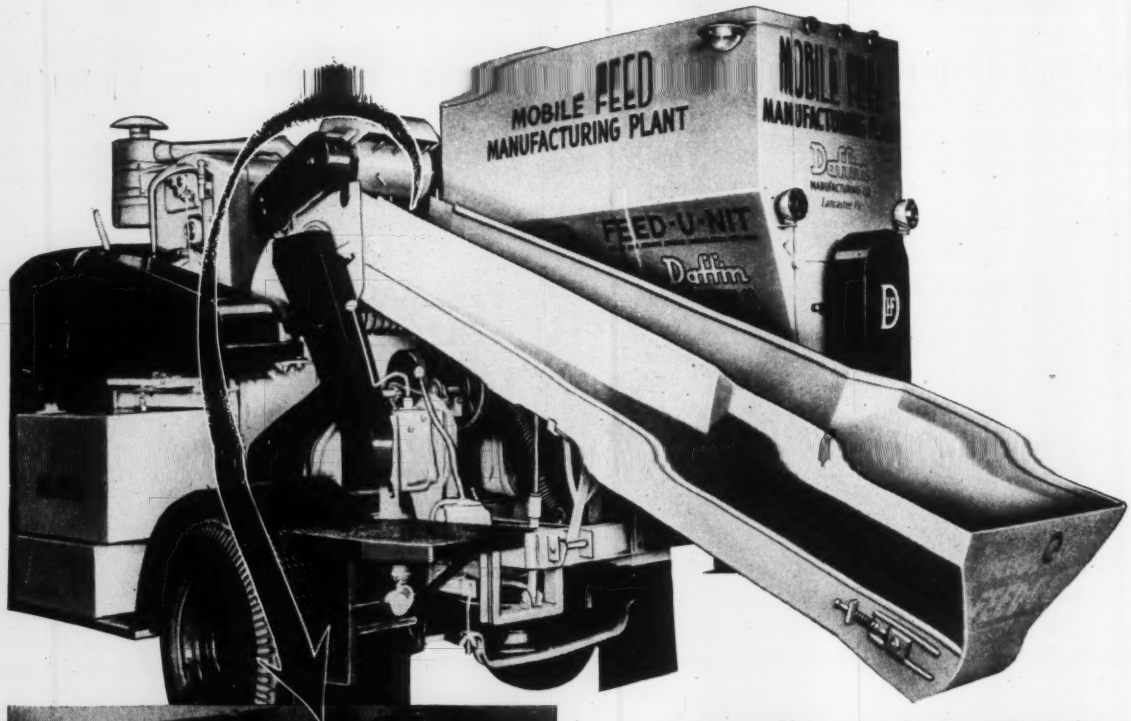
A DIVISION OF STEPHENS-ADAMSON MFG. CO., 18 RIDGEWAY AVE., AURORA, ILLINOIS

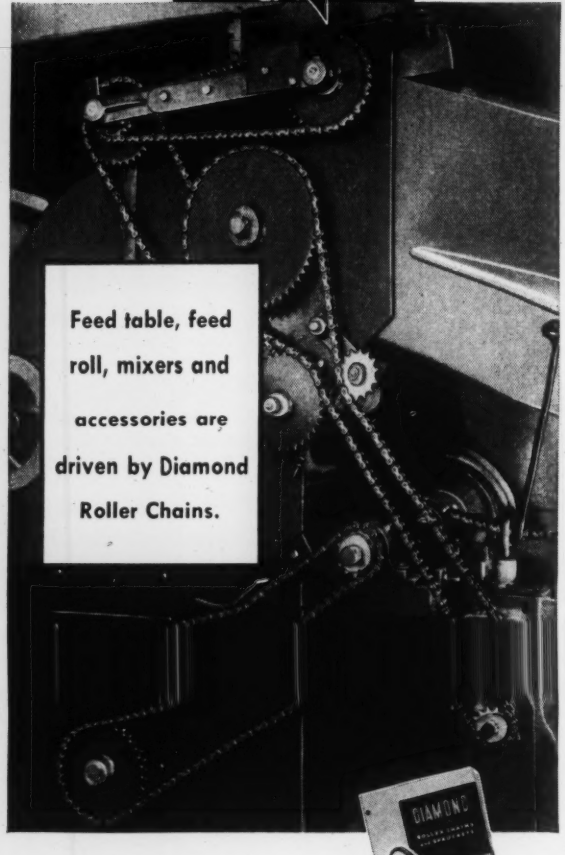
—ITEM 521—

For More Information Circle Item Number on Yellow Card—page 19

DIAMOND ROLLER CHAIN DRIVES

on Daffin Mobile Grinding and Mixing Plant





Feed table, feed roll, mixers and accessories are driven by Diamond Roller Chains.

A Traveling Feed Manufacturing Plant—Employs Diamond Roller Chain Drives to Coordinate Complete Operation

For maximum dependability and operating economy, the Daffin Mobile Feed-U-Nit employs Diamond Roller Chains for feed table, feed roll, mixer and accessory drives. Their light weight, compact size, great uniform strength and flexibility of application permit positive drives regardless of shaft center distances or speed ratios. Shock loading is spread over many sprocket teeth, bearing pressures are eliminated. These design features are especially important in mobile farm equipment where repair facilities are often remote.

For any roller chain application, specify Diamond—their uniform highest quality is your assurance of economical operation.

DIAMOND CHAIN COMPANY, Inc.
Where High Quality is Traditional
Dept. 435, 402 Kentucky Ave., Indianapolis 7, Ind.
Offices and Distributors in All Principal Cities

Catalog 754 contains 64 pages of engineering data. Write for your copy.

DIAMOND **ROLLER CHAINS**

—ITEM 522—
For More Information Circle Item Number on Yellow Card—page 19

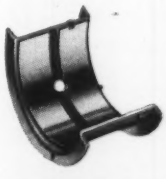
Open or closed, straight or clinch butted, or special seams.
Lengths from ⅛" to 5". I.D. from ⅛" to 1½". Any standard plating desired.
Special design features are easily incorporated in these spacers, rolled from steel strip.
Holes, windows, cutouts or notches to meet your needs. Ball indented O. D. available.
Rolled Split Steel Spacer Tubes
Infinite Design Variations . . . for a Multitude of Industrial Jobs!

Delivered ready for assembly—no costly cut-off or de-burring. Save the cost of pipe or tubing. No scrap or material handling or inventory! You can save purchasing time, too—645 standard lengths, diameters and gauges. Special designs available. Send for free catalog and price list.

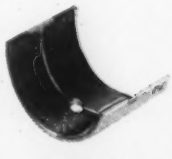
FEDERAL-MOGUL

DIVISION, Federal-Mogul-Bower Bearings, Inc.
11045 Shoemaker, Detroit 13, Michigan

BEARING-SURFACED THRUST WASHERS


BABBITT-LINED BEARINGS

PLAIN & BIMETAL SPLIT BUSHINGS


COPPER-LEAD BEARINGS

FEDERAL Mogul
SINCE 1899

RESEARCH • DESIGN • METALLURGY • PRECISION MANUFACTURING

What do Machine Builders like most about SQUARE D's New Machine Tool Relays?...

SMALL SIZE!

Class 8501
Type DO-22

No wonder the welcome mat is out for these new 10-ampere, 600-volt relays. You've always had a warm spot in your heart for COMPACTNESS... and here it is! Let the dimensions speak for themselves—

2-pole Type DO-22 *(at left)*
measures 3 5/16" high x 2 5/8" wide!

4-pole Type DO-42 *(below)*
measures 3 11/16" high x 2 13/16" wide!

But that isn't all. You take these relays apart, in 20 seconds, *from the front.* No "tear down" space is needed—absolutely none!

Class 8501
Type DO-42

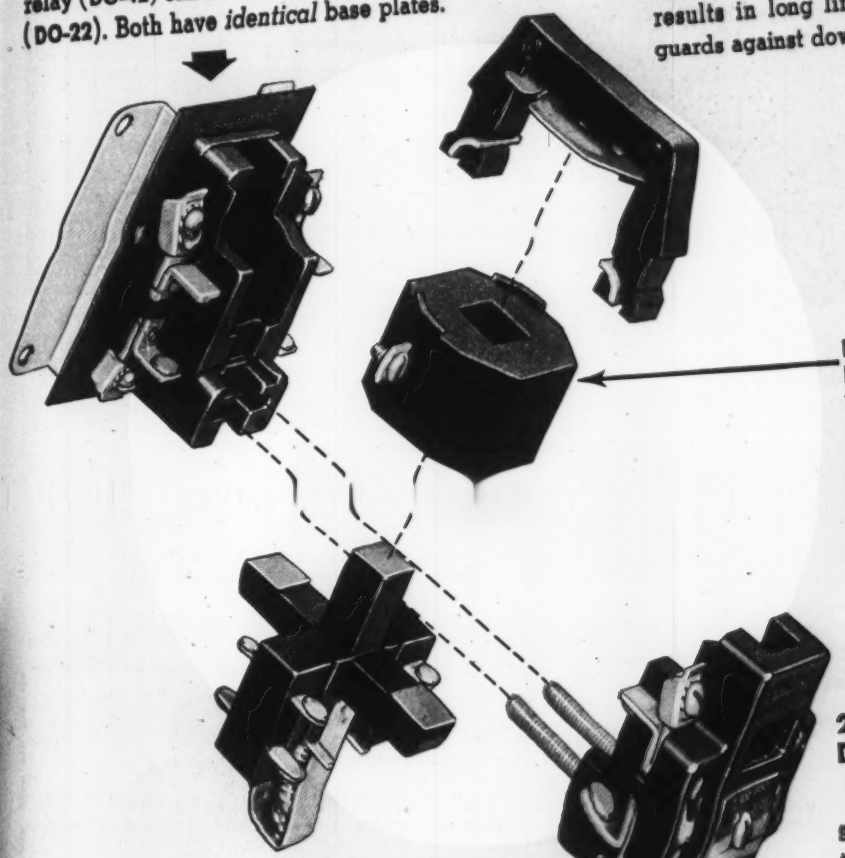
Small size isn't the only reason machine tool builders welcome these new relays. Anything that's good for their customers is good for them—so they're not overlooking advantages like those shown on the opposite page. After all, there's something mighty satisfying about the customer's nod of approval when he sees the time-proven D nameplate on the relays that help control his new machine.

SQUARE D COMPANY

And these 4 Advantages make real sense to the men who *BUY* and *USE* the machines!

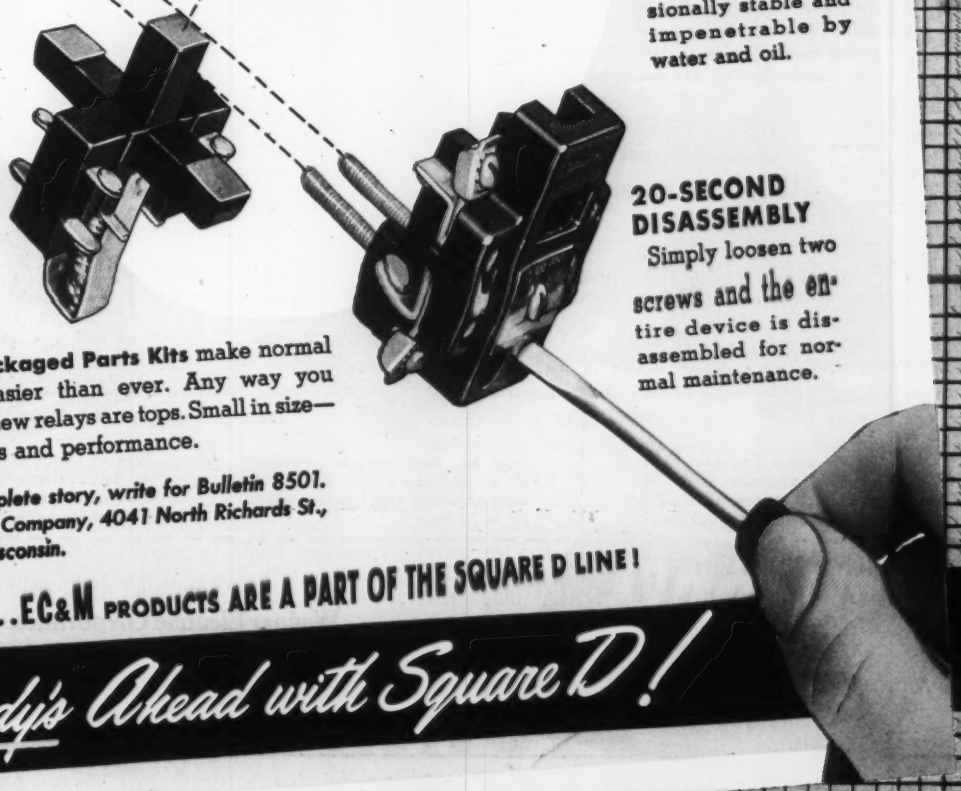
NO MOUNTING WORRIES
When more contacts are required, the 4-pole relay (DO-42) can be substituted for the 2-pole (DO-22). Both have *identical* base plates.

OUTSTANDING PERFORMANCE
Balanced construction reduces wear on single moving part... results in long life and safeguards against down time.



RESISTS DAMAGE
Plastic impregnated molded coil is unbreakable, operates cooler, is dimensionally stable and impenetrable by water and oil.

20-SECOND DISASSEMBLY
Simply loosen two screws and the entire device is disassembled for normal maintenance.



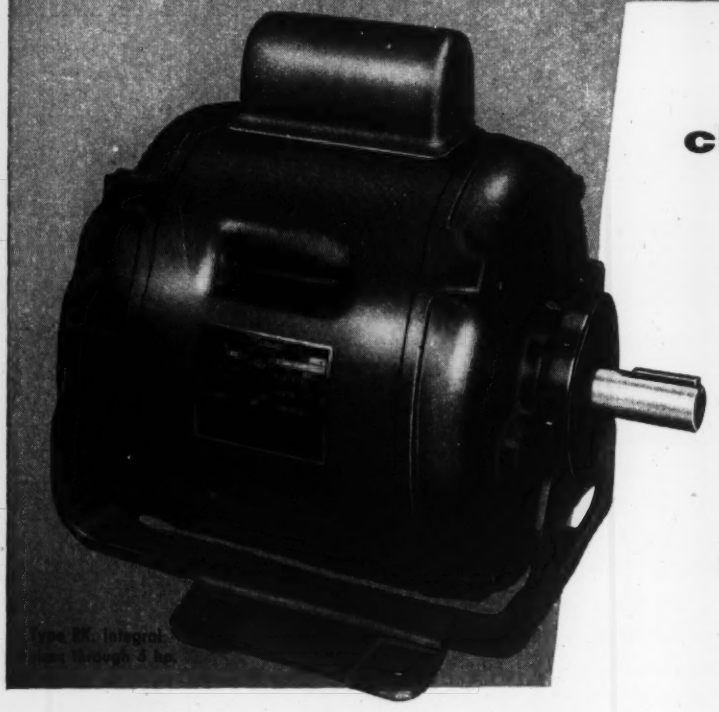
Packaged Parts Kits make normal maintenance easier than ever. Any way you look at it, these new relays are tops. Small in size—long on features and performance.

For the complete story, write for Bulletin 8501. Address Square D Company, 4041 North Richards St., Milwaukee 12, Wisconsin.

NOW...EC&M PRODUCTS ARE A PART OF THE SQUARE D LINE!

Everybody's Ahead with Square D!

WAGNER ELECTRIC MOTORS...THE CHOICE OF LEADERS IN INDUSTRY



choose these smaller, lighter, motors... for modern equipment

For years Wagner motors have been the first choice of many leading manufacturers of air conditioners, refrigerators, freezers, water pumps and motor-driven tools. They meet the requirements of many other similar applications because of their high starting torque and low starting current.

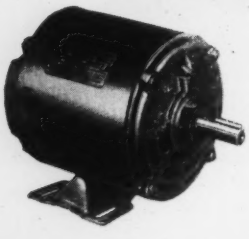
Now these Wagner motors are lighter in weight and smaller in size. This means that you can design smaller motor housings—build lighter motor mountings. Wagner motors are easier to handle and easier to stock because they take up less space.

And these motors offer low maintenance costs—only a minimum of servicing is required—they give many years of reliable service with unusual freedom from vibration and noise.

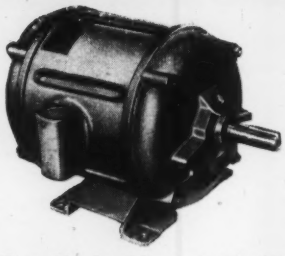
Available in repulsion-start or capacitor-start types

—open or totally-enclosed—sleeve or ball bearing—with rigid or resilient bases or machined endplates for flange mounting. Write today for Bulletin MU-185 which gives complete information.

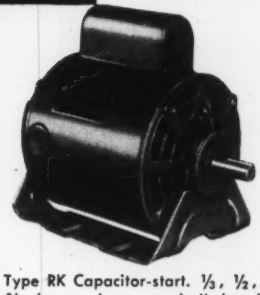
A Complete Line—Single-phase and Polyphase Motors



Type RP, Polyphase fractional horsepower motors. Available in 1/6, 1/4, 1/3, 1/2, and 3/4 hp ratings. Rigid or resilient base—sleeve or ball bearing.



Type RA, Repulsion-start induction-run single-phase motors. For applications requiring high starting torque. 1/2 to 15 hp.



Type RK Capacitor-start. 1/3, 1/2, and 3/4 hp . . . sleeve or ball bearings. The resilient mounting offers unusual freedom from vibration and noise.

Wagner Electric Corporation
EST. 1891

Wagner Electric Corporation
6404 Plymouth Ave., St. Louis 14, Mo., U.S.A.

BRANCHES AND DISTRIBUTORS IN ALL PRINCIPAL CITIES

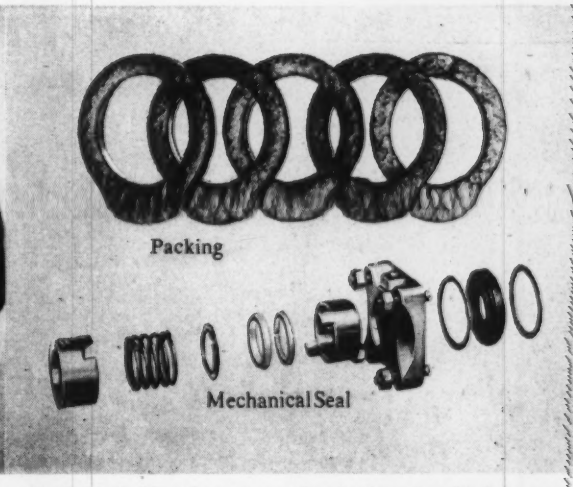
ELECTRIC MOTORS • TRANSFORMERS • INDUSTRIAL BRAKES • AUTOMOTIVE BRAKE SYSTEMS-AIR AND HYDRAULIC

M56-5

—ITEM 525—
For More Information Circle Item Number on Yellow Card—page 19

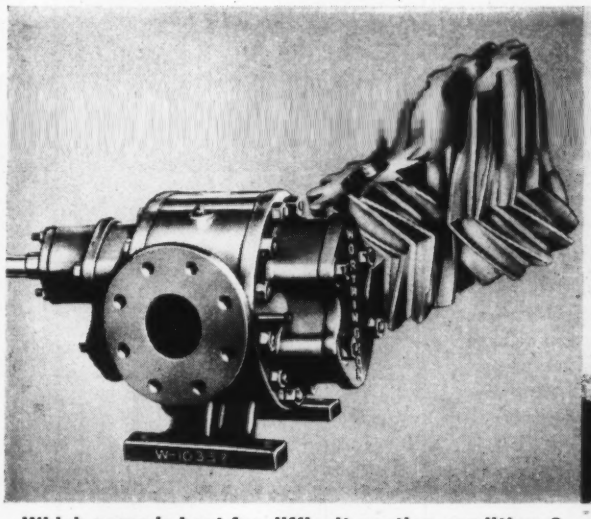
WHAT'S YOUR P.Q.?*

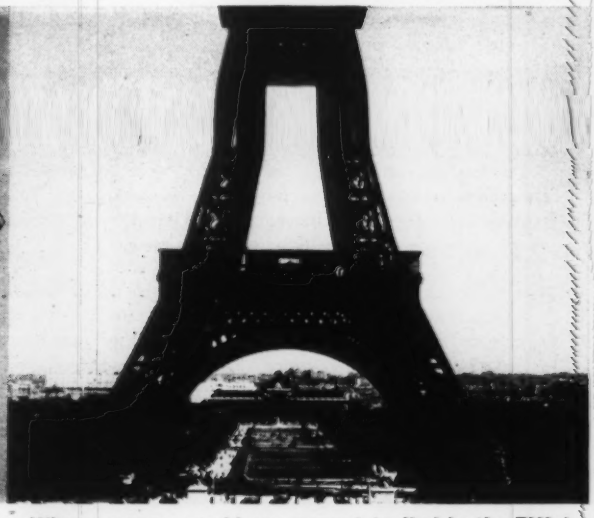
*PUMP QUOTIENT



Pump standardization—how do you benefit? By standardizing, you can often drastically cut your spare parts inventory. With Worthington's SESC (Standard End Suction Centrifugal) line, you are also assured of immediate delivery from factory or distributor stocks. Because the SESC line consists of standardized "parts" not "pumps," it can be built in many different combinations . . . 70,480 to be exact. For all these reasons, more and more companies are turning to SESC pumps. See bulletin W-300-B4.

Packed stuffing box or mechanical seal—which is preferred? Each has its applications. Mechanical seals are gaining in popularity year after year. With Worthington's Standard End Suction Centrifugal pumps you not only get your choice of mechanical seals—or packing—but you can easily convert from one to the other using standard stock parts. This "interchangeability" is just one of the many extra advantages of Worthington's SESC line. For more details write for bulletins W-300-B4 and W-350-B16.





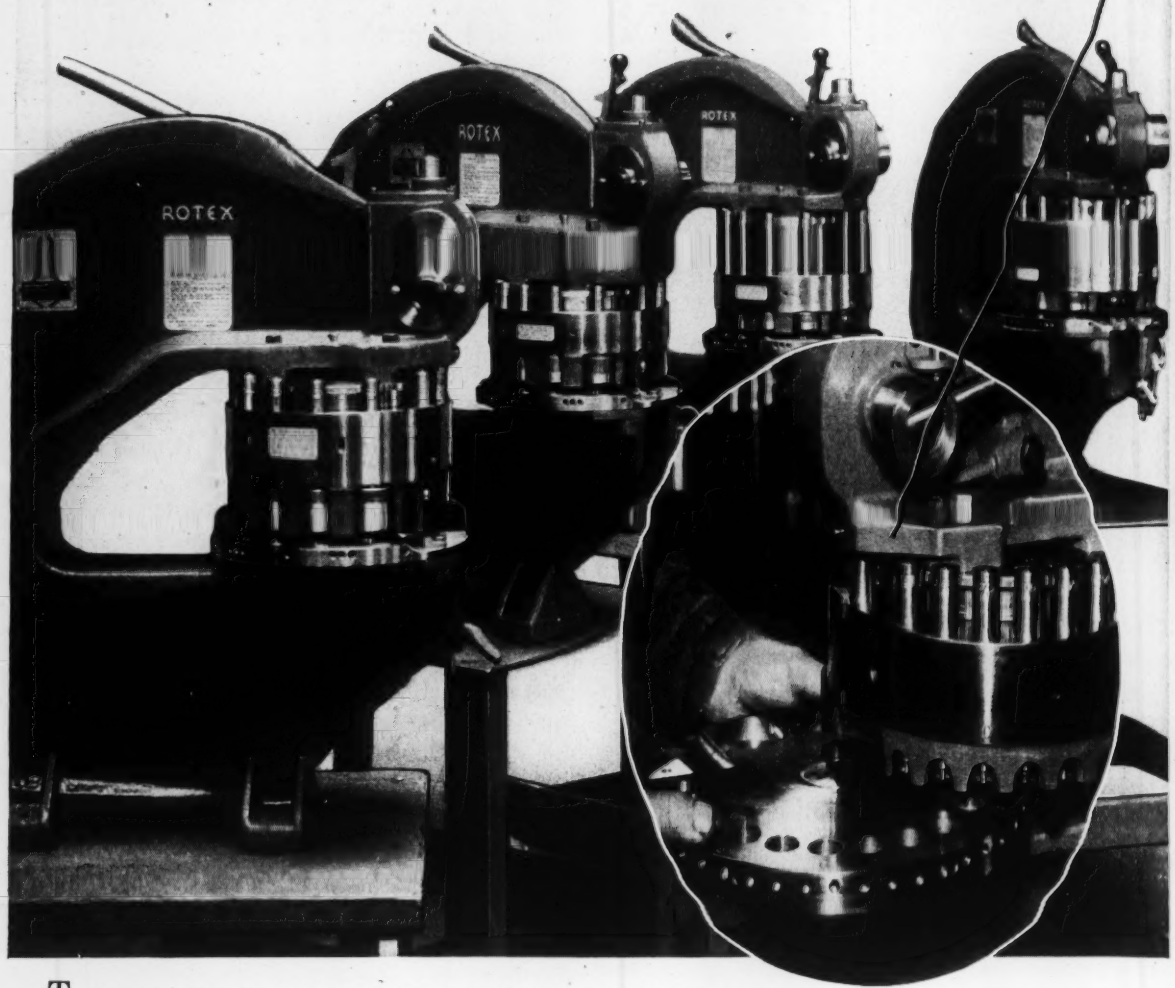
Which pump is best for difficult suction conditions? Worthington's close-clearance rotary pump is self-priming and can operate under vacuums as high as 28 inches of mercury. The large unobstructed suction opening in this herringbone gear pump permits operation with thin or viscous liquids at high efficiency. The double-helical gears balance all end thrust, eliminate trapping of liquid between gear teeth and provide a quiet, pulsation-free flow at high speeds. For the full story, ask for bulletin W-483-B2.

Whose pumps would you expect to find in the Eiffel Tower? If you said "Worthington's," your P.Q. is all right. The original steam-driven pumps that power the Eiffel Tower's 100-passenger hydraulic elevators were built by Worthington back in 1889. The most recent additions, modern electric-drive Worthington pumps, moved into the Tower just last year. Today as then, wherever men must move liquid, they turn to the company with a reputation for performance. Worthington Corp., Harrison, N. J. PC. 6.5

WORTHINGTON

—ITEM 526—

SPEED CASE steel makes better products at lower costs



THE die turret plate of the Rotex Quick Change Punch press is machined from Speed Case Steel Plate.

This machine, manufactured by the Rotex Punch Company of Oakland, California, owes its versatility to a rotary turret—the quick change feature. The turret is rotated to the desired punch size and locked into position. The dies and punches are accurately pre-aligned to insure maximum precision.

Sheet Metal Shops and metalworking plants have found the Rotex Punch Press a time-saving cost-cutting unit because of this unique design.

The exceptional machinability of Speed Case low carbon free machining open hearth steel provides this manufacturer with more highly finished parts, reduced machining time, much improved tool life, a minimum of distortion in machining and heat treating—and most important an improved product at lower cost.

Ask for our New Speed Steel Plate Bulletins:

Bulletin 541— SPEED CASE	low carbon free machining open hearth steel plate
Bulletin 542— SPEED TREAT	medium carbon free machining open hearth steel plate
Bulletin 543— SPEED ALLOY	High quality chrome-manganese alloy steel plate

THE SPEED STEELS ARE DISTRIBUTED COAST TO COAST BY THESE WAREHOUSES

Beals McCarthy & Rogers, Inc.
Buffalo, N. Y.

Bridgeport Steel Co.
Milford, Conn.

Brown-Wales Co.
Cambridge, Mass.

Burger Iron Co.
Akron • Dayton, Ohio

Grammer, Dempsey & Hudson, Inc.
Newark, N. J.

W. J. Holliday & Co. Division
Indianapolis, Ind.

Earle M. Jorgensen Co.
Los Angeles • Oakland • San Francisco • Houston • Dallas • Tulsa

Peninsular Steel Co.
Detroit, Mich.

Pidgeon-Thomas Iron Co.
Memphis, Tenn.

Horace T. Potts Co.
Philadelphia • Baltimore

Jones & Laughlin Steel Warehouse Division
Chicago • Cincinnati • Louisville

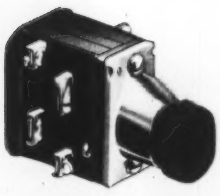
W. J. HOLLIDAY & CO.

DIVISION OF JONES & LAUGHLIN STEEL CORPORATION
SPEED STEEL DIVISION • INDIANAPOLIS 7, INDIANA

—ITEM 527—
For More Information Circle Item Number on Yellow Card—page 19

Facing Page—ITEM 528→

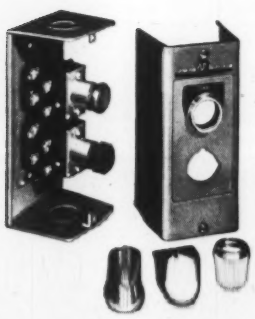
ALLEN-BRADLEY
HEAVY DUTY PUSH BUTTONS



Bulletin 800 heavy duty STOP button ready to mount in enclosure. (See below)

These new Bulletin 800 heavy duty push buttons are the modernized version of that old reliable line of A-B heavy duty stations. Advantages—until now restricted to the oiltight stations for machine tool use—have been built into these new heavy duty stations—and you'll like the result.

For instance, each button or pilot light is a self-contained unit which can be mounted singly or in groups—vertically or horizontally—in a variety of standard Allen-Bradley enclosures, with the name plate reading in the right direction. Double break, silver alloy contacts used throughout. Send for Bulletin 800.



A small stock of standard components lets you assemble any **special heavy duty station.** There is no waiting for special push button stations.

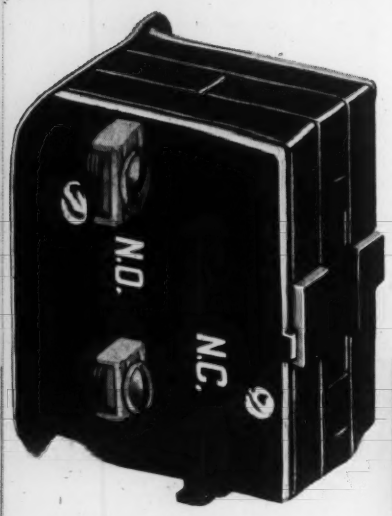
5-56-MR

Allen-Bradley Co., 1316 S. Second St.
Milwaukee 4, Wisconsin

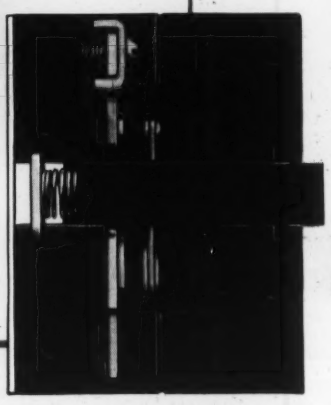
In Canada
Allen-Bradley Canada Ltd., Galt, Ont.

A-B Quality

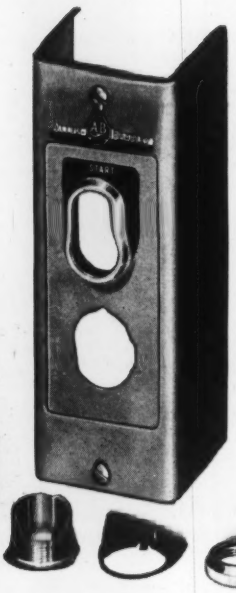
ALLEN-BRADLEY
QUALITY
BULLETIN 800 PUSH BUTTONS

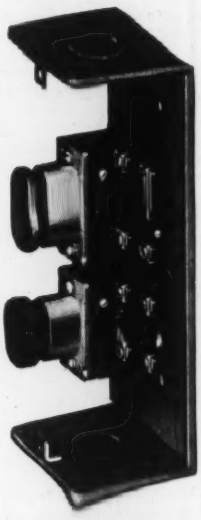


Left—External view of contact block showing N. O. & N. C. terminals.



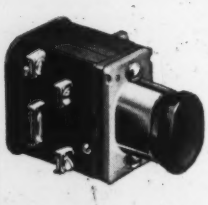
Right—Internal view of contact block showing double break N.O. & N.C. stationary contacts. The pushrod carries the moving contacts.



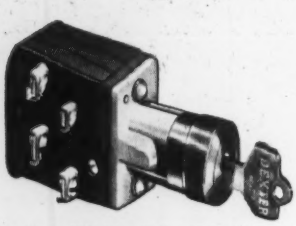


Two button station with name plate and clamping ring removed from cover.

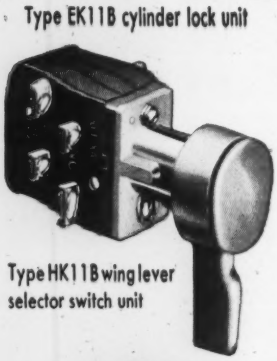
A NEW LINE OF ALLEN-BRADLEY HEAVY DUTY PUSH BUTTONS



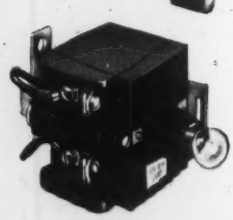
Type AK1B flush head START button



Type EK11B cylinder lock unit



Type HK11B wing lever selector switch unit



Type PK16 pilot light with 110 v, 60 cy. transformer. Available with 220-440-550 v, 60 & 25 cy. transformer

Allen-Bradley heavy duty push buttons have been redesigned to take advantage of the type of construction that has made A-B oiltight machine tool stations so popular.

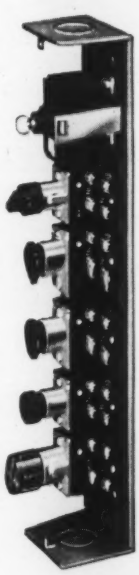
While the new Bulletin 800 heavy duty line is not oiltight, it uses contact blocks that have proved so dependable in the Bulletin 800T oiltight push buttons. Special heavy duty stations can be assembled on the job from a small stock of standard components.

Several types of operators are available, such as standard head, mushroom head, coin slot, key type, wing lever, and 2 or 3 position selector switches. The buttons can be supplied in different colors.

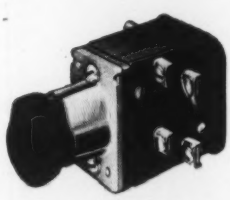
These push button stations can be easily arranged for either vertical or horizontal mounting —with the name plates reading correctly for the desired mounting.

Standard enclosures accommodate up to 8 buttons and pilot lights. Enclosures for more than 8 units can be supplied. Write for Bulletin 800.

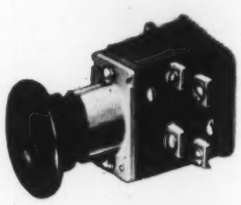
Allen-Bradley Co.
1316 S. Second St.
Milwaukee 4, Wis.
In Canada
Allen-Bradley Canada Ltd.
Galt, Ont.



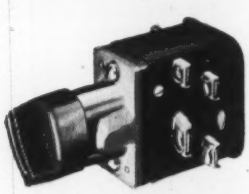
Five button station with pilot light



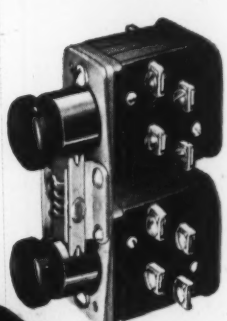
Type BK6B ext. head STOP button



Type DK6B mushroom head button



Type HK2B selector switch



Type FK2B 2 button interlocked station

5-56-MR

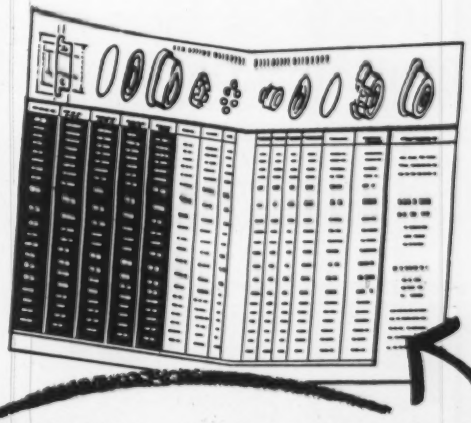
If you work with small instrument type bearings you'll find this new, authoritative publication an extremely valuable and handy source of engineering data arranged in convenient form for practical reference.

LOOK AT THESE FEATURES . . .

- A helpful survey article: "FACTORS TO CONSIDER IN SELECTING SMALL INSTRUMENT BALL BEARINGS."
- A complete, practical presentation of bearing facts:

Types of bearings	*Lubrication*
Materials	*Applications*
Components	*Radial and Axial play*
Engineering standards	*Torque*
Tolerances	*Mounting practice*
Dynamic and static loads	*etc.*

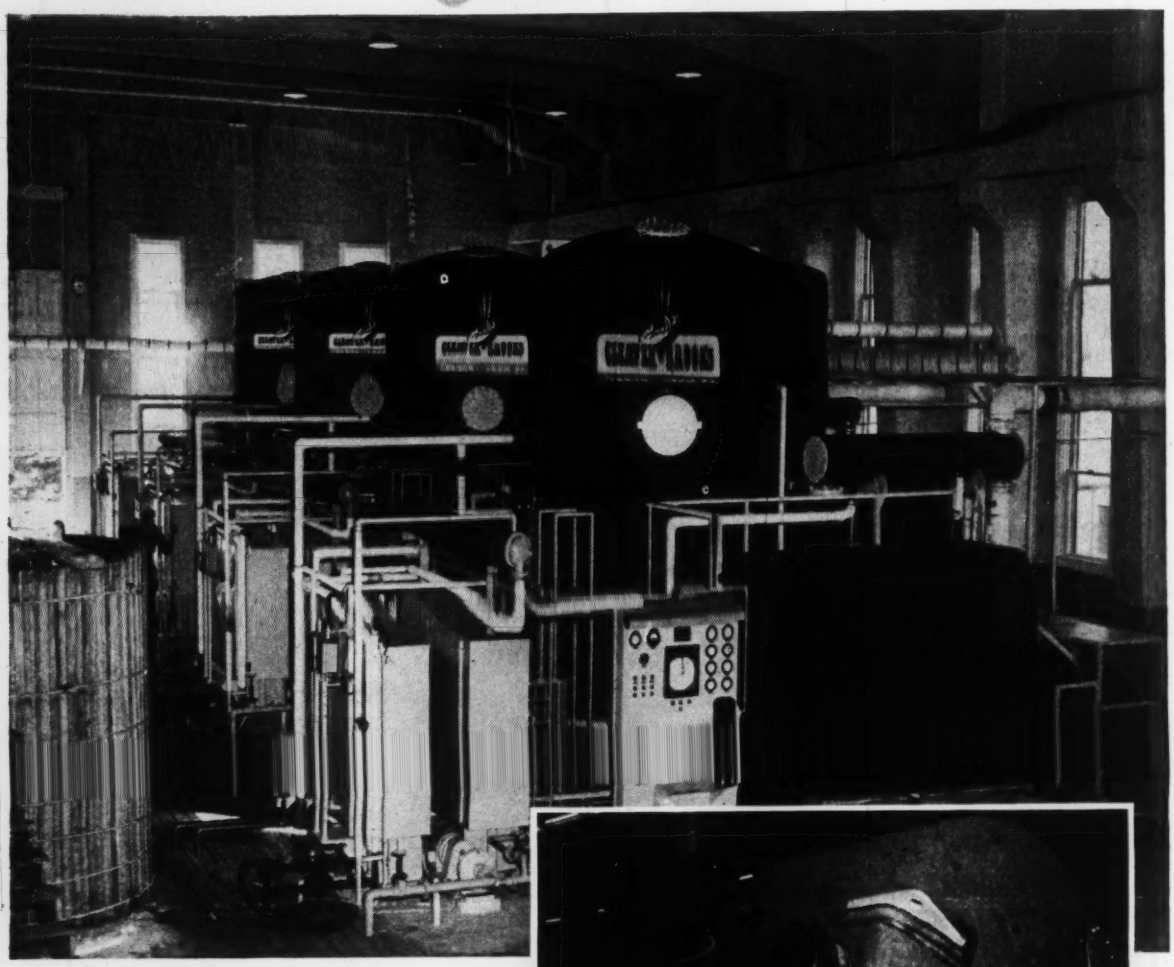
- Large, clear illustrations.
- Big, easy to follow charts.
- Convenient nomographs and conversion charts.
- Simple bearing designations make ordering easy.



WRITE TODAY... GET YOUR NAME ON OUR PRIME DISTRIBUTION LIST FOR MAILING SOON-"HOT OFF THE PRESS"!

—ITEM 529—
For More Information Circle Item Number on Yellow Card—page 19

World's



BATTERY OF CLEAVER-BROOKS EVAPORATORS IN ACTION—Revere Silicon Bronze was chosen for these evaporators and their component parts because of its high corrosion resistance and non-contamination properties, great strength and weldability. All of the components, as well as the 4 evaporator shells, are made of Revere Silicon Bronze Alloy No. 420.

ONE OF THE 4 EVAPORATOR SHELLS made of Revere Silicon Bronze, fabricated and installed by CLEAVER-BROOKS MFG. CORP., Waukesha, Wisconsin.

EIGHT TUBE SHEETS LIKE THESE were used in the Bermuda installation . . . 2 per evaporator. Each tube sheet, made of Revere Silicon Bronze, is 86" in diameter, 1¼" thick and weighed approximately 1,360 lbs. after drilling.

Largest

VAPOR-COMPRESSION SEA WATER DISTILLATION PLANT

Made and installed by CLEAVER-BROOKS

. . . Vital distillation units fabricated from

REVERE SILICON BRONZE

This plant installed at the Kindley Air Force Base in Bermuda has a total daily capacity of 200,000 gallons and eliminates the dependence of the Base on rainfall or shipment of water by tankers.

Distilled water is produced in the ratio of 300 lbs. to each pound of Diesel fuel. Total costs are estimated at $1.25 per thousand gallons of distilled water. Nearly every component part made by Cleaver-Brooks is about twice the size of its largest previous counterpart. For example, the evaporators are 16½ feet high. Each, with its component parts, weighs approximately 40,000 lbs., the empty Revere Silicon Bronze shell alone accounting for 28,000 lbs.

There is an interesting story behind the development and manufacture of this equipment. The four huge pressure vessels had to be fabricated of Revere Silicon Bronze Alloy No. 420. Knowing Revere's wide experience in welding copper-base alloys, Cleaver-Brooks called in a Technical Advisor, and gave him a complete set of blueprints of the vessels, with a request for suggestions regarding joint design and welding techniques. He in turn consulted the Welding Section of the Revere Research Department. Their recommendations were adopted, and the customer reported that the original estimate of welding time had been cut considerably, reducing production costs correspondingly.

The Revere Technical Advisory Service is glad to collaborate on problems involving the specification and fabrication of copper and copper-base alloys, and aluminum alloys. See the nearest Revere Sales Office.

REVERE COPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

230 Park Avenue, New York 17, N. Y.

Mills: Baltimore, Md.; Brooklyn, N. Y.; Chicago, Clinton and Joliet, Ill.; Detroit, Mich.; Los Angeles and Riverside, Calif.; New Bedford, Mass.; Newport, Ark.; Rome, N. Y. Sales Offices in Principal Cities, Distributors Everywhere.

COPPER * BRASS * 18 01 * REVERE * ALUMINUM *

THE STEAM SEPARATORS are identified by their conical tops and directional vanes. They are of the cyclone type, which is a patented feature of CLEAVER-BROOKS evaporators, and remove entrained water from the steam, thus preventing contamination of the fresh water coming from this unit. The result is an extremely high purity of the fresh water product.

The rectangular objects at rear of photograph are the "Downcomers" which bring water down from the top of the steam separator. The tubes in left foreground are "Hotwells," which receive the distilled water discharge from the evaporator shell.

—ITEM 530—
For More Information Circle Item Number on Yellow Card—page 19

New Lightweight All-Angle MonoMotor

Redmond

AM-4 MONOMOTOR

4-POLE, Up to 16 Watts

Extra large oil reservoir permanently sealed for LIFETIME LUBRICATION

ACTUAL SIZE

Here are the outstanding features of this single bearing motor designed specifically for the refrigeration and air conditioning industries and adaptable for a multitude of other applications where a long life quality motor is required.

1. Lightweight—Durable, lightweight metal used in construction makes the AM-4 considerably lighter than conventional old style models.

2. All-Angle Operation—Designed for all-position mounting, vertical shaft up, shaft down, or any angle.

3. Interchangeability—Will accommodate all standard brackets and special mountings.

4. New Positive Oil System—Forced recirculation of oil. 25 cc of lubricant completely suspended and uniformly distributed in pure wool and nylon wicks, permanently sealed, to guarantee against oil leakage in use or shipment.

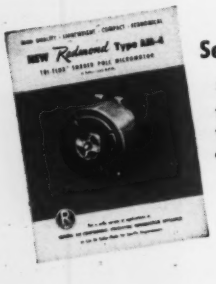
5. Controlled End Play—Special thrust arrangement accurately controls rotor end play.

6. Whisper-Quiet—Smooth, quiet operation assured through use of steel-backed precision bored bearing inserts, uniform air gap, and extremely close manufacturing tolerances.

7. Tri-Flux® Design—Greatly increases starting and running torque and improves efficiency over conventional small diameter motors.

8. Uni-Cast® Construction—Gives a rugged, lightweight motor that can be manufactured to extremely close tolerances, with stator core frame precision die cast in one piece, registers are machined concentric to the bore to extremely close tolerances.

9. TWO-YEAR WARRANTY—Here you have a motor designed to meet modern demands and to give you outstanding performance over years of continuous service-free use. Your assurance of customer satisfaction is backed by Redmond's full two-year warranty.



Send for Complete Performance Data

Write for the "AM-4 Bulletin"—it contains complete information on the design features, dimensions, performance, and operational data.

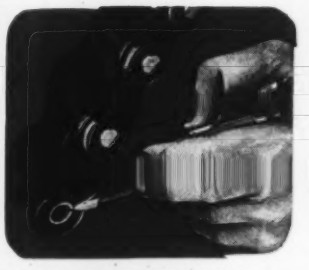
The Standard of Dependability

Redmond COMPANY Inc.
OWOSSO, MICHIGAN

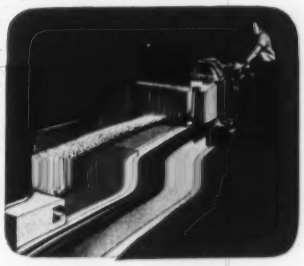
ADVERTISED IN The Saturday Evening POST

THE BIG NAME IN SMALL MOTORS

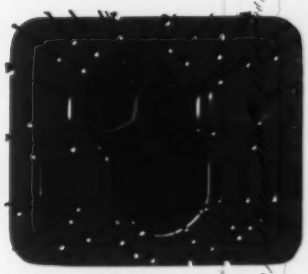
—ITEM 531—
For More Information Circle Item Number on Yellow Card—page 19



LOCK-TYPE BUSHINGS (applied on a range of sizes) end a common cause of stiff chain.

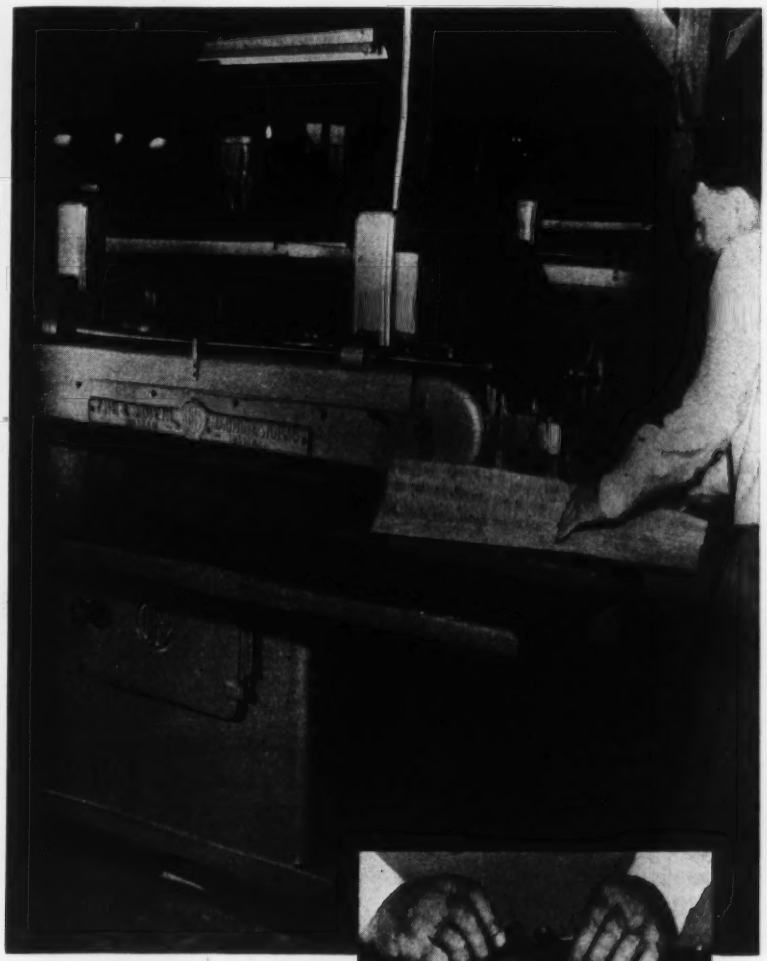


PRE-STRESSING of multiple width chain provides uniform load distribution.



SHOT-PEENED ROLLERS have greater fatigue life, added ability to withstand impact.

How these LINK-BELT EXTRAS make roller chains last longer



THERE's more to roller chain than just the parts you see. *Much more!* There are the hidden extras—standard on Link-Belt Precision Steel Roller Chain—that add up to longer life and lower costs.

Throughout every stage of manufacture, Link-Belt takes *extra* care to build *extra* life into Precision Steel Roller Chain. Shown above are three of these added refinements . . . and there are many others which contribute to better performance and longer life for your machines.

There's complete application information on roller chains in 148-page Data Book 2457. Ask your nearby Link-Belt office for your copy.

You can choose from a wide range of Link-Belt roller chains and sprockets. In addition, Link-Belt's complete line includes silent chain drives . . . and all sizes and types of cast, combination, forged and fabricated steel chains.

Feed chain on this Model 890 tapeless veneer splicer made by the G. M. Diehl Machine Works, Inc., Wabash, Ind., is Link-Belt Roller Chain. Machine joins the edges of veneer strips from 1/64 to 3/16 inch thick in one simple operation at speeds up to 85 fpm.

LINK-BELT

CHAINS and SPROCKETS

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. To Serve Industry There Are Link-Belt Plants, Sales Offices, Stock Carrying Factory Branch Stores and Distributors in All Principal Cities. Export Office: New York 7; Canada, Scarboro (Toronto 13); Australia, Marrickville, N.S.W.; South Africa, Springs. Representatives Throughout the World. LB.030

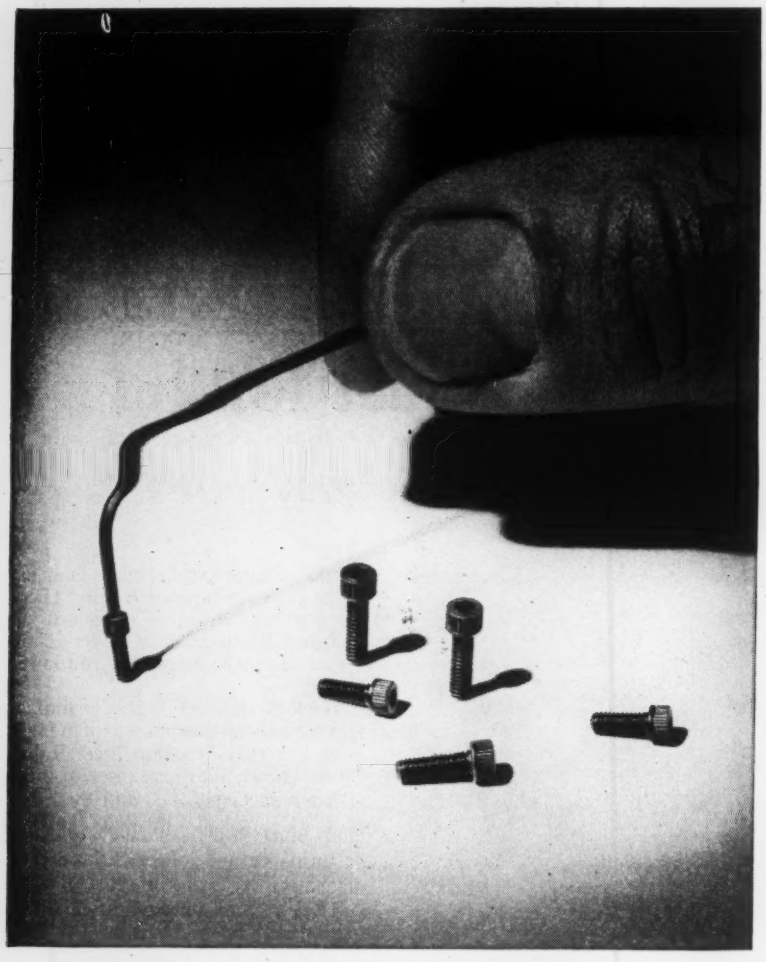
No one chain serves every purpose . . . get the RIGHT one from Link-Belt's complete line

Silent Chain | LXS Steel Chain | Detachable Steel Link-Belt | S-815 Flat-Top Chain | Cast and Cut-Tooth Sprockets

—ITEM 532—

For More Information Circle Item Number on Yellow Card—page 19

Miniature screws aid standardization of small devices



Standard UNBRAKO miniature socket head cap screws are available in sizes # 0, # 1, # 2 and # 3, in heat treated alloy steel or stainless steel, at your authorized industrial distributor's. Standard lengths range from ⅛ to ½ in.

Tiny close-tolerance

Unbrako screws available in standard sizes

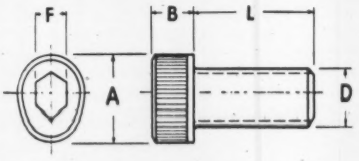
New economies in the design of space-saving miniature equipment are possible with these UNBRAKO miniature socket head cap screws. Manufactured to timepiece precision, available locally, they save the costly necessity of designing special screws to fasten tiny parts in compact units. They're ideal for use in typewriters, calculators and computers, servomechanisms, electric and electronic equipment—and in countless other small, intricate devices where maximum reduction in bulk and weight is required with no sacrifice in strength of individual components or assemblies.

Fingers grip the knurled heads on these tiny screws positively for easy handling and fast assembly. Uniform hex sockets assure maximum wrenching torque. Controlled fillets under the heads prevent shearing of the heads. Threads are fully formed for maximum strength and exact fit. Extremely accurate head diameters permit their use in countersunk holes, saving weight by reducing the length of the screw required and making flush designs possible.

These standard UNBRAKO miniature screws are available at your authorized industrial distributor's. See him today. Or write us for Bulletin 2055 and samples. Unbrako Socket Screw Division, STANDARD PRESSED STEEL Co., Jenkintown 18, Pa.

HEAT-TREATED ALLOY STEEL

Class 3 Fit Standard



	Diameter	Threads per Inch NC	Threads per Inch NF	Length	Recommended Installation Torque in Inch-Pounds NC	Recommended Installation Torque in Inch-Pounds NF	Weight per 1000 in Pounds
#0	A .104		80	⅛		2.0	.152
	B .060		80	3/16		2.0	.182
	D .060		80	¼		2.0	.210
	F .050		80	⅜		2.0	.265
#1	A .118		72	⅛	3.5	3.5	.27
	B .073		72	3/16	3.5	3.5	.32
	D .073		72	¼	3.5	3.5	.37
	F .050		72	⅜	3.5	3.5	.47
#2	A .140	56		3/16	6.0	6.0	.42
	B .086	56		¼	6.0	6.0	.50
	D .086	56		⅜	6.0	6.0	.58
	F 1/16	56		½	6.0	6.0	.70
#3	A .161	48		3/16	8.5	9.5	.59
	B .099	48		¼	8.5	9.5	.70
	D .099	48		⅜	8.5	9.5	.81
	F 5/64	48		½	8.5	9.5	1.03

Standard Screws are threaded to the head. Special materials, lengths, and threaded lengths are available. One "High-Titan" UNBRAKO hex key is included with each package of 100 screws.

UNBRAKO®

SOCKET SCREW DIVISION

STANDARD PRESSED STEEL CO.

SPS

JENKINTOWN PENNSYLVANIA

—ITEM 533—

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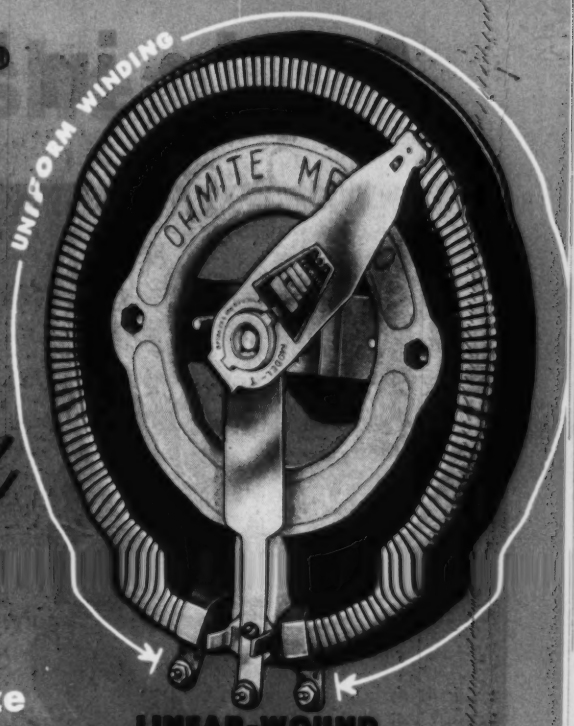
Facing Page—ITEM 534→

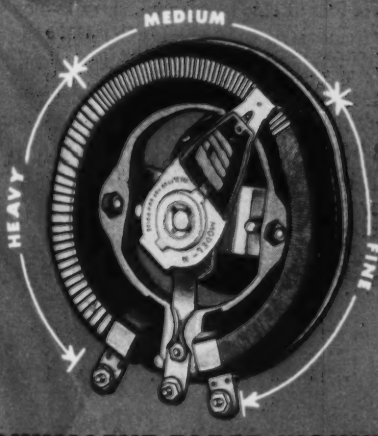
OHMITE®

taper-wound RHEOSTATS

reduce rheostat size required

Tapering the wire size to match the current carried permits greater capacity in a smaller unit!





A smaller rheostat may often be used for a given load by having the rheostat windings tapered or wound in two or more sections of diminishing wire sizes. This can be done because only **the first turn of the winding carries the maximum current . . .** succeeding turns carry reduced amounts. This makes possible great savings in control-panel space, making Ohmite taper-wound rheostats particularly useful in portable equipment. Ohmite taper-wound rheostats are also very durable because they use the largest wire sizes practical for the current to be carried.

MORE UNIFORM CONTROL—For a given application, the tapered winding also provides more uniform control. Because a linear-wound rheostat adds a constant number of ohms per degree of rotation to a constantly increasing number of ohms, the current changes more slowly as the resistance is increased. A tapered winding, by increasing the number of ohms per degree of rotation as the total ohms in circuit increases, makes the current curve more nearly linear.

Ohmite has an extensive line of standard tapered rheostats, or will design special tapered windings to suit individual needs.

Write on company letterhead for Catalog and Engineering Manual No. 40.

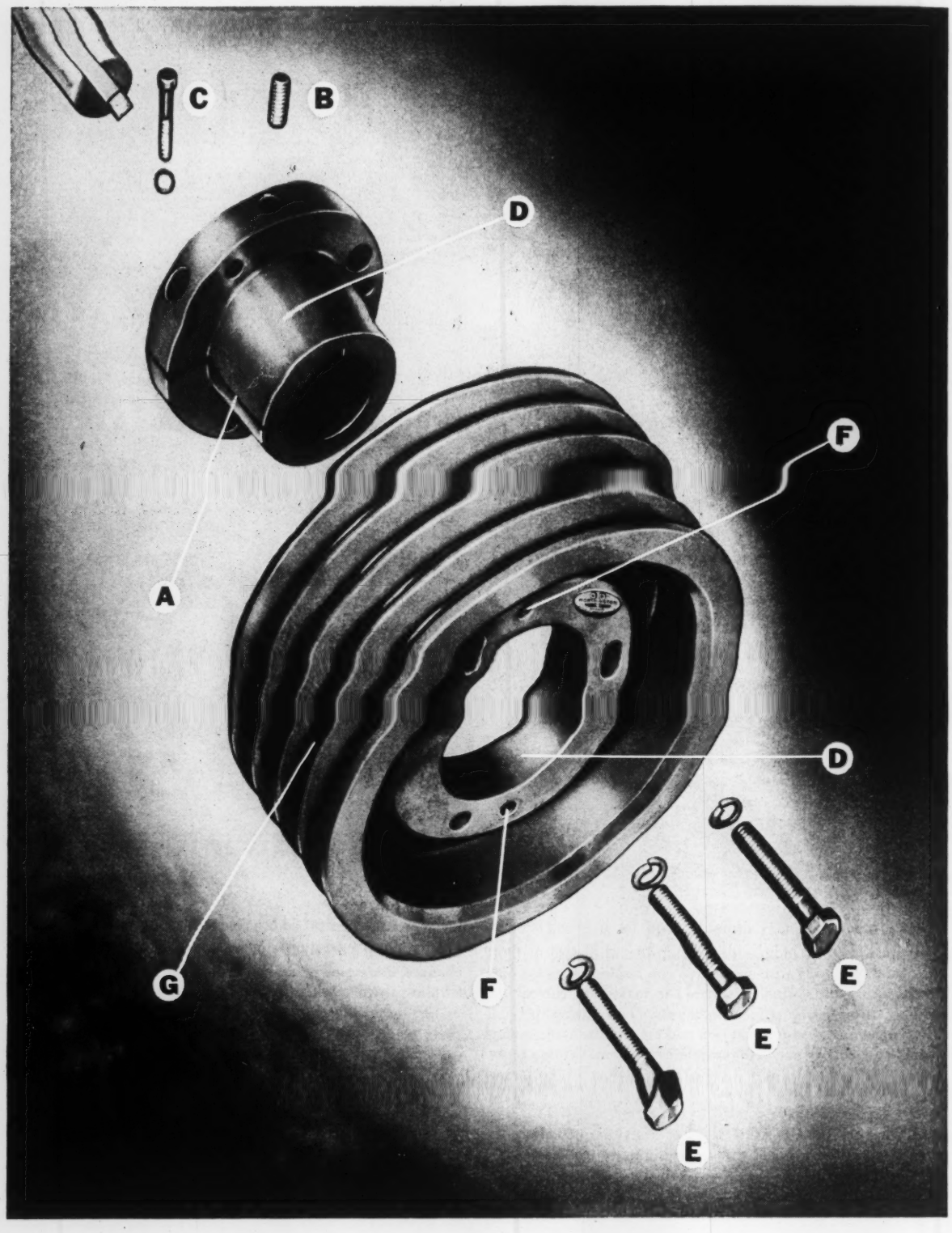
OHMITE MANUFACTURING COMPANY, 3618 Howard Street, Skokie, Illinois (Suburb of Chicago)

MORE OHMITE RHEOSTATS SOLD THAN ALL OTHER MAKES COMBINED

Be Right with **OHMITE®**

RHEOSTATS • RESISTORS • RELAYS • TAP SWITCHES

Again in '55, industry's



Exclusive design. All Worthington QD sheaves have these outstanding product features:

A- Completely split QD hub holds shaft tightly under heaviest shock loads.

B- Cup point set screw* in QD hub keeps shaft key in position.

C- Clamp screw* secures hub in proper alignment on shaft when mounting sheave.

D- Tapered fit between hub and sheave allows easy-on, easy-off, hold-tight action.

E- Pull-up bolts draw sheave on to hub to produce positive fit on shaft.

F- Tapped holes in sheave permit pull-up bolts to be used as jack screws to break cone grip when removing sheave.

G- Groove cross-sections are accurate and uniform so that each V-belt seats properly, pulls evenly.

**All Worthington-manufactured QD heavy duty hubs incorporate these exclusive features*

best selling sheave

9 outstanding features make Worthington QD the favorite of design engineers

According to authoritative industry figures, more QD sheaves were sold last year than any other type. Design engineers tell us they prefer the QD—the original two-piece design—because of these 9 outstanding features:

1 EXCLUSIVE DESIGN. As shown at left, Worthington QD sheaves have many outstanding product features which mean real benefits to all users.

2 EASY TO INSTALL AND REMOVE, the QD's tapered hub slides on shaft, locks with a cap screw for permanent alignment. Sheave slides on hub and pulls up with three big bolts for tight holding. Comes off just as easily.

3 BALANCED PERFORMANCE of Worthington Multi-V-Drives, due to accurate uniform grooves and precise mating (with Worthington-Goodyear V-belts), gives you even tension, even pull, even speed, even wear, less vibration.

4 SMART APPEARANCE. The QD sheave's scientific design not only provides more efficient transmission of power but actually adds to the looks of your product.

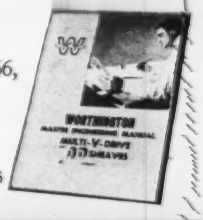
5 QUICK DEPENDABLE SERVICE—factory-warehouses back distributors.

6 MATCHES YOUR QUALITY STANDARDS. QD sheave quality stems from extremely accurate balance, tough close-grained semi-steel metal, rigid inspection for minimum tolerances, and "I-beam" arm construction of driven sheaves which gives greater strength with less weight.

7 WIDE RANGE OF SIZES with factory-warehouse stocks covering over 100,000 V-belt drive combinations from ½ to 600 hp.

8 WIDE RANGE OF APPLICATIONS. QD sheaves have been job-tested and accepted on every class of equipment and in every industry. Some of the many applications in which QD sheaves have given outstanding performances include: blowers, boring mills, compressors, conveyors, crushers, elevators, grinders, lathes, stokers, oil field machinery and many, many others.

9 COMPLETE ENGINEERING DATA—yours for the asking. In Worthington's 100-page manual, tabbed, easy-to-find tables enable you to select the right sheave and V-belt combination for any job in only three minutes. For your free copy write to Section MV66, Worthington Corporation, Oil City, Pa. In Canada: Worthington (Canada) 1955, Ltd., Toronto, Ont. MV.6.6



Over 400 stock Worthington-Goodyear V-belt sizes.

Over 100,000 drive combinations available from warehouse stocks.

13 factory-warehouses back more than 250 distributors.

WORTHINGTON

SPECIFY THESE WORTHINGTON STANDARD PRODUCTS ON YOUR EQUIPMENT

Compressors • Pumps • Multi-V-Drives • Variable Speed Drives

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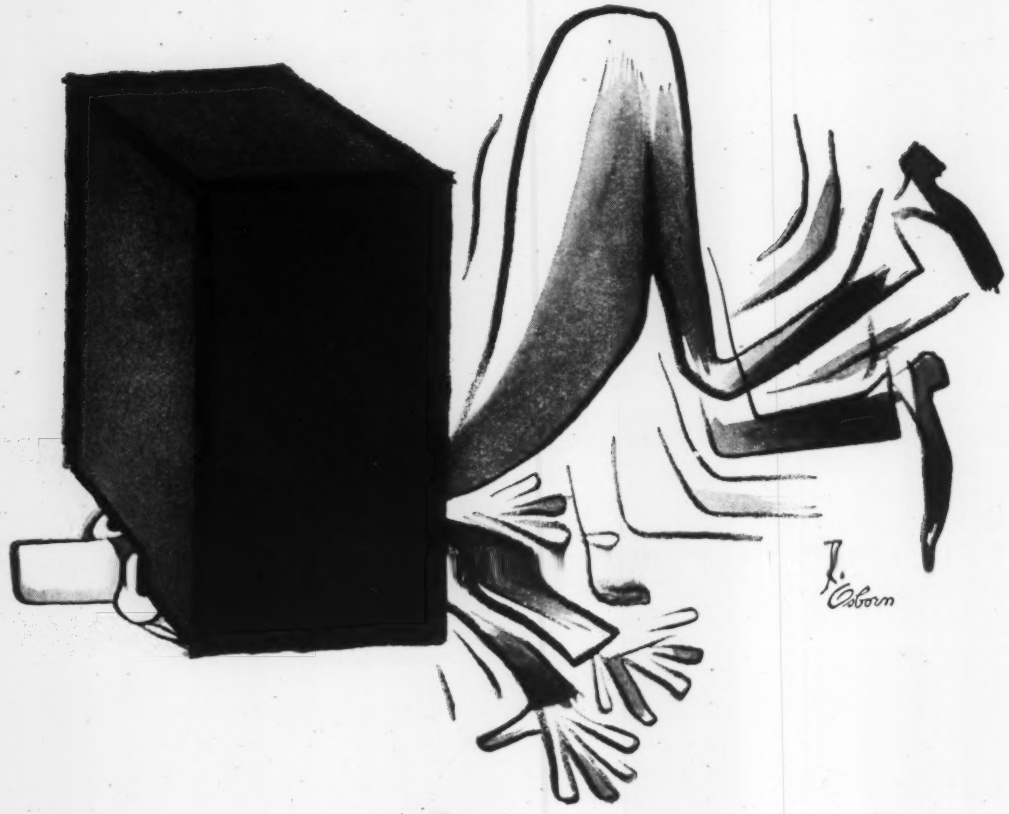
For More Information Circle Item Number on Yellow Card—page 19



Got a LOAD on Your mind?

Burdened down with a problem in design diminution, weight reduction, power capsulation? Lighten the load on your mind—send for the amazing story on how MPB's* such as these

BALL BEARINGS ACTUAL SIZE

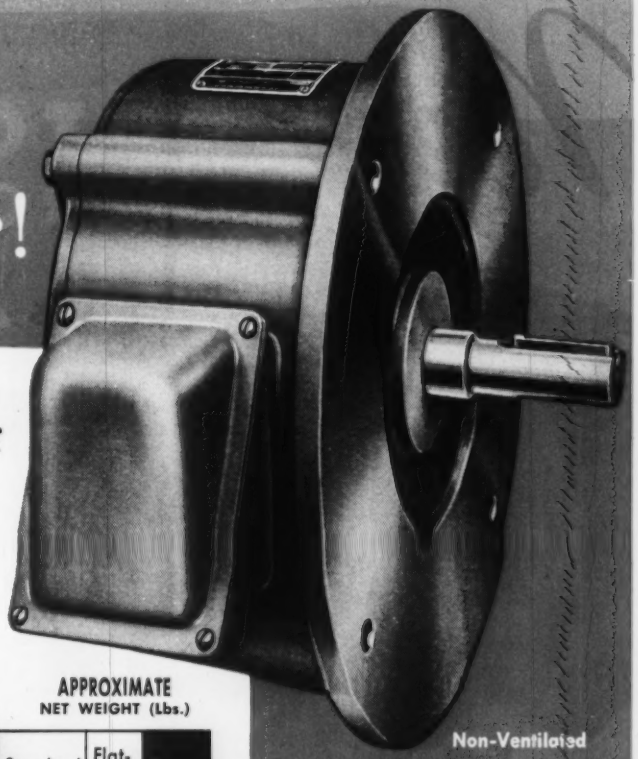
make

a breeze.

*MINIATURE PRECISION BEARINGS, INC.

3 Precision Park, Keene, New Hampshire

The Motor you asked for!



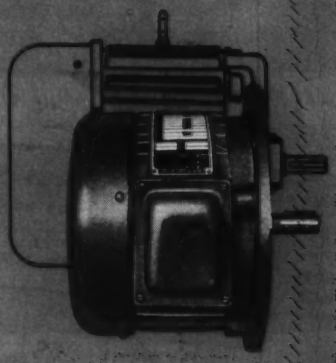
Non-Ventilated

TAKES less space... because it's the new FLAT-Type Motor

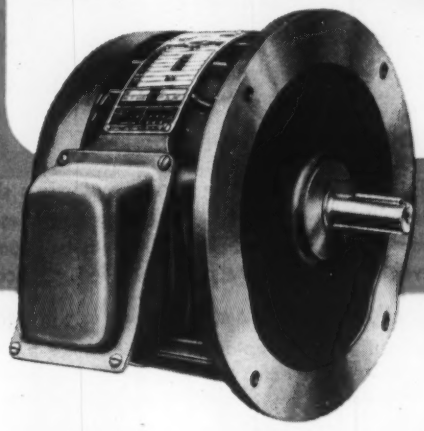
GIVES more service... because it's a DIEHL

FOR SIZE AND WEIGHT, COMPARE THE NEW FLAT-TYPE WITH STANDARD MOTORS

FRAME SIZE		OVERALL LENGTH (Inches)			APPROXIMATE NET WEIGHT (Lbs.)		
Standard	Flat-Type	Standard	Flat-Type	Saving	Standard	Flat-Type	Saving
DIF 182	DIF 180	14 1/16	10 3/4	3 5/16	82	59	23
DIF 213	DIF 220	17 3/16	11 9/16	5 5/8	128	83	45
DIF 284U	DIF 280	26	13 13/16	12 3/16	272	135	137



New Flat-Type superimposed on standard motor



Fan Cooled

The unique and perfect answer in *integral motors*—designed especially for the machine tool and equipment industries.

Packs full horsepower in less space . . . actually up to 48% shorter than standard motors without sacrifice in performance. Many pounds lighter, too, than conventional motors (over 50% in some cases), meaning vastly reduced over-hung weight. Standard radial construction, easy to disassemble and reassemble . . . no precision alignments or complicated air-gap adjustments to contend with. Totally-enclosed . . . no dirt, dust or moisture can get in.

Available (non-ventilated) in ratings to 3 H.P., and (fan-cooled) in ratings to 20 H.P.

Perhaps the Diehl Flat-Type Motor is just what you need to solve your application problems. Give us the details and we'll be glad to submit recommendations.

Ask for your copy of Bulletin MD-3461.

Diehl

DIEHL MANUFACTURING COMPANY

Electrical Division of THE SINGER MANUFACTURING COMPANY

Finderne Plant, SOMERVILLE, NEW JERSEY

ATLANTA • BALTIMORE • CHARLOTTE, N. C. • CHICAGO • CINCINNATI • DETROIT • MILWAUKEE • NEEDHAM, MASS. • NEW YORK • PHILADELPHIA • PITTSBURGH

—ITEM 537—

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New ROTO-MATION TORQUE MOTOR

4 COST-CUTTING ADVANTAGES

For Oil or other Pressure Mediums.
Pressure Against Vane Reciprocates Shaft.

TYPICAL TORQUE RATINGS (IN.-LBS.)
Single Vane Units—280° Arc both directions

BORE SIZE	Vane Length	100 PSI	500 PSI	1000 PSI	WT. LBS.
3"	2"	150	750	1500	15
	4"	300	1500	3000	21.5
	6"	450	2250	4500	28
6"	3"	1000	5000	10,000	92
	6"	2000	10,000	20,000	104
10"	5"	5000	25,000	50,000	286
	8"	8000	40,000	80,000	312
	12"	12,000	60,000	120,000	387
20"	6"	30,000	150,000	300,000	1620
	12"	60,000	300,000	600,000	2100

NOTE: Double Vane Units double torque with same pressures, but rotation is limited to 100° in both directions.

✓ HIGHER TORQUE OUTPUT—special neoprene and teflon vane seals minimize leakage . . . insure greater power. Speeds limited only by H.P. pressure volume. Full torque power obtainable in fraction of a second.

✓ GREATER OPERATING EFFICIENCY—through superior design of special vane seals and close tolerance fitting of all parts. Operates at 95 to 98% efficiency, withstands heat up to 200°F. Special models and seals for higher temperatures.

✓ SIMPLE, ECONOMICAL APPLICATION—eliminates complex linkages, sprockets, chains, cylinders. Saves space. Applicable to turning, opening, closing, clamping, indexing, feeding, pushing, or moving any type of load or mechanism.

✓ LONGER SERVICE LIFE—fewer moving parts, precision machined components, bronze nut and thrust bearings, chrome vanadium and chrome-moly steel shafts. No external leakage.

COMPACT, RUGGED, ADAPTABLE TO A WIDER RANGE OF APPLICATIONS

The new ROTO-MATION Oscillating Torque Motor is a simple, more versatile hydraulic-pneumatic device especially designed to produce more torque power (1,800,000 in.-lbs. from 20" bore) to serve a wider variety of automation applications. Compact and rugged, the new motor is easily adaptable to original equipment or as a replacement unit. Wide ports and flange-type connections meet J.I.C. standards. Extensive tests prove that performance life is many times greater than any device previously manufactured. The square shape facilitates easy mounting on any of six faces. There are 14 mounting models available and four shaft styles. Units are complete with standardized controls, fittings, and auxiliary devices. Sizes are available for moving loads ranging from a few ounces to many tons.

Write **FOR COMPLETE SPECIFICATIONS**—New catalog provides complete specifications, illustrates and describes wide variety of applications, and contains complete torque load graphs.

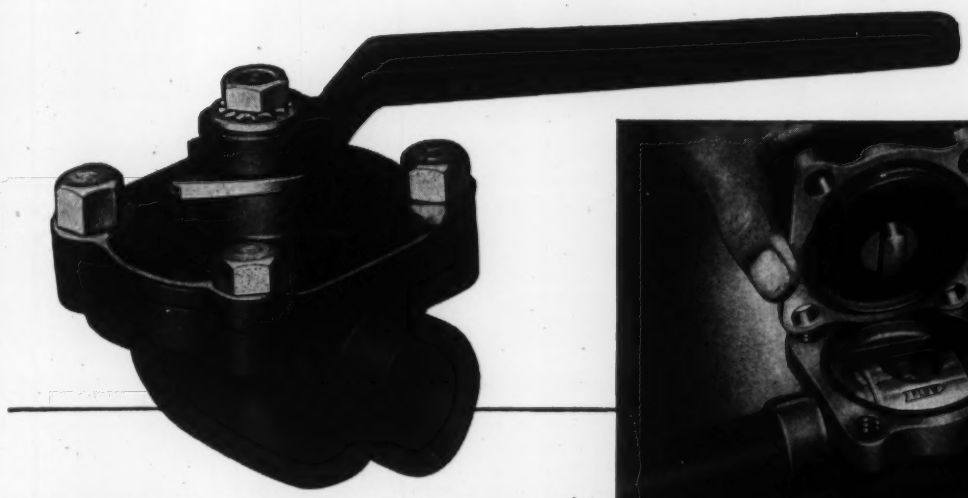
ROTO-MATION INC.

NOW A SUBSIDIARY OF PINES ENGINEERING CO., INC.

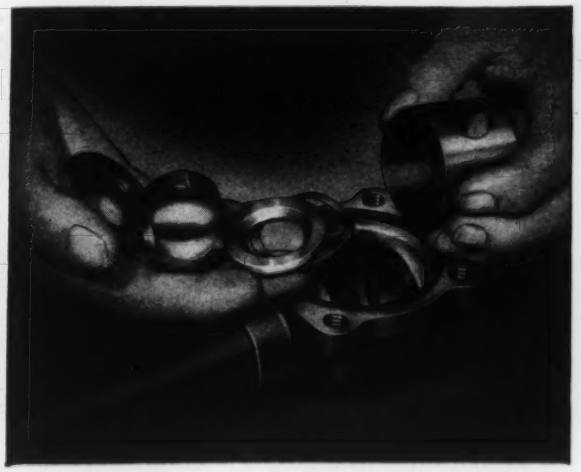
947 E. SATER STREET • GREENVILLE, OHIO

ATION MOTORS, CONTROLS, AND AUXILIARY TRANSMISSION EQUIPMENT

—ITEM 538—



FAST, LOW-COST CHANGE IN DIRECTION OF FLOW. Removal of the body cap permits reversing the cage assembly to allow change in direction of flow. In addition, this feature lets you change seat material, and clean the valves thoroughly and quickly — *without removing the valve from the line!*



INTERCHANGEABILITY of seat material to meet your operating requirements is another feature of the Rockwood Top Entry Ball Valve. Seat can be furnished in Buna-N, Neoprene, Kel-F, Teflon, and Nylon.

EASY INSTALLATION AND OPERATION is permitted because of the new handle design. This new design allows the handle to be placed in any of *eight positions!*

Now!... New Rockwood Top Entry Ball Valve

. . . A new concept in valves that saves you money and time!

Made of bronze the new Rockwood Top Entry Ball Valve is ideal for handling oxygen and hazardous liquids as well as water, oil and gas. It carries 300 lbs. per square inch on water, oil and gas and 400 lbs. per square inch on LP gas and is available both with sweat ends and screw ends, in sizes ½", ¾" and 1".

Write for complete data on this unique full round pipe size flow.

ROCKWOOD BALL VALVES

FULL, ROUND FLOW

Distributors in all Principal Industrial Areas

ROCKWOOD SPRINKLER COMPANY
1221 Harlow Street
Worcester 5, Mass.

Please send me complete information on Rockwood Top Entry Ball Valves.

Name.....

Title.....

Company.....

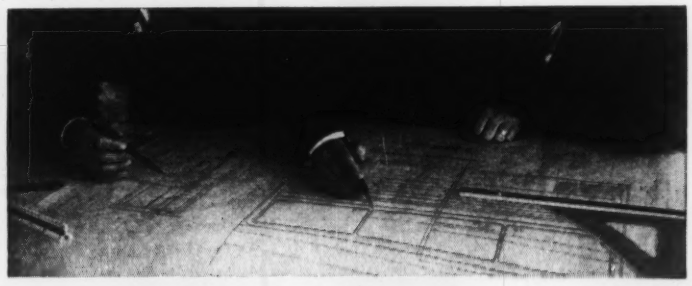
City.....

Zone....State.....

MONSANTO

Today's industrial designers face a dual challenge in the race to outdistance competition. Their products must be more pleasing in appearance, more efficient in performance. Many of these designers are working closely with plastics engineers in the custom molding industry to achieve both goals simultaneously. Read how one of America's leading manufacturers of air conditioning units improved sales in a fiercely contested market by utilizing the unique properties offered by plastic materials.

New housings of Lustrex Styrene plastic are building business for Fresh'nd-Aire



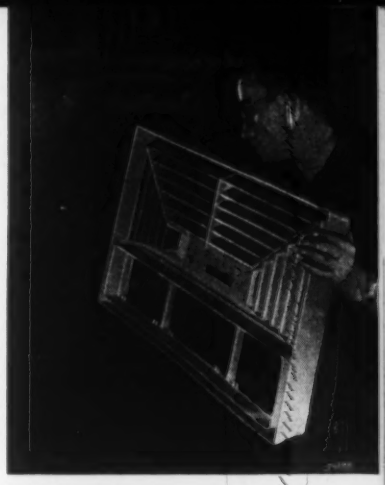
DESIGN OBJECTIVES. In creating a new line of air conditioning units, the management of the Fresh'nd-Aire Company, division of the Cory Corporation, Chicago, required an interior housing with many advanced features. The new housing had to have sleek decorating styling to make it an outstandingly handsome piece of furniture. It had to incorporate tight-fitting removable parts. It also had to be produced at reasonable cost.

MATERIAL SPECIFICATION. Careful testing by Fresh'nd-Aire engineers proved that Lustrex high impact styrene offered the most desirable characteristics. A styrene housing could be economically produced with an attractive, soft-lustered, surface-to-surface coloring in the specified shade. This eliminated six costly painting and cementing operations. Injection molding techniques for high impact styrene freed designers from the restrictions of metal die-stamping machines. Modern smooth-flowing lines could be obtained. There was no danger of rust or corrosion deteriorating the housing. Furthermore, Lustrex high impact styrene provided a strong base for rivets, bolts and other anchoring devices. This tough Monsanto styrene also demonstrated its ability to hold critical dimensions. Parts like reversible vents and a front cover accessory panel could be removed and replaced repeatedly without the hazard of bending out of snug fit.

PRODUCTION ENGINEERING. General American Transportation Corporation, Chicago, was commissioned to supply the styrene housing for Fresh'nd-Aire. Every design requirement was satisfactorily met by molding the component of Monsanto Lustrex Hi-Test 88, a rubber-modified high-impact styrene. The part is produced in a hydraulic 1500-ton press and contains 40 ounces of the Monsanto styrene material.

THE FINISHED PRODUCT. The new Fresh'nd-Aire unit has earned the hearty approval of both trade and public. Sales officials agree the change to styrene components has improved the marketability of the line. The interior housing and exclusive "Style-Gard" accessory panel have added vital style interest to the unit—and improved its performance. A 300% sales increase over last year is anticipated for the 1956 season.

This is one of hundreds of design and production problems which have been solved by utilizing the facilities of the plastics custom molding industry. These 20th Century craftsmen are available to manufacturers designing for greater efficiency and lower costs. As a major supplier of plastic resins, Monsanto is in a position to introduce you to custom molders who will put their skills to work for you. If you are considering a design change for your product line, be sure to investigate plastics. Write to Monsanto Chemical Company, Industrial Applications Dept., Room 607, Springfield 2, Mass.

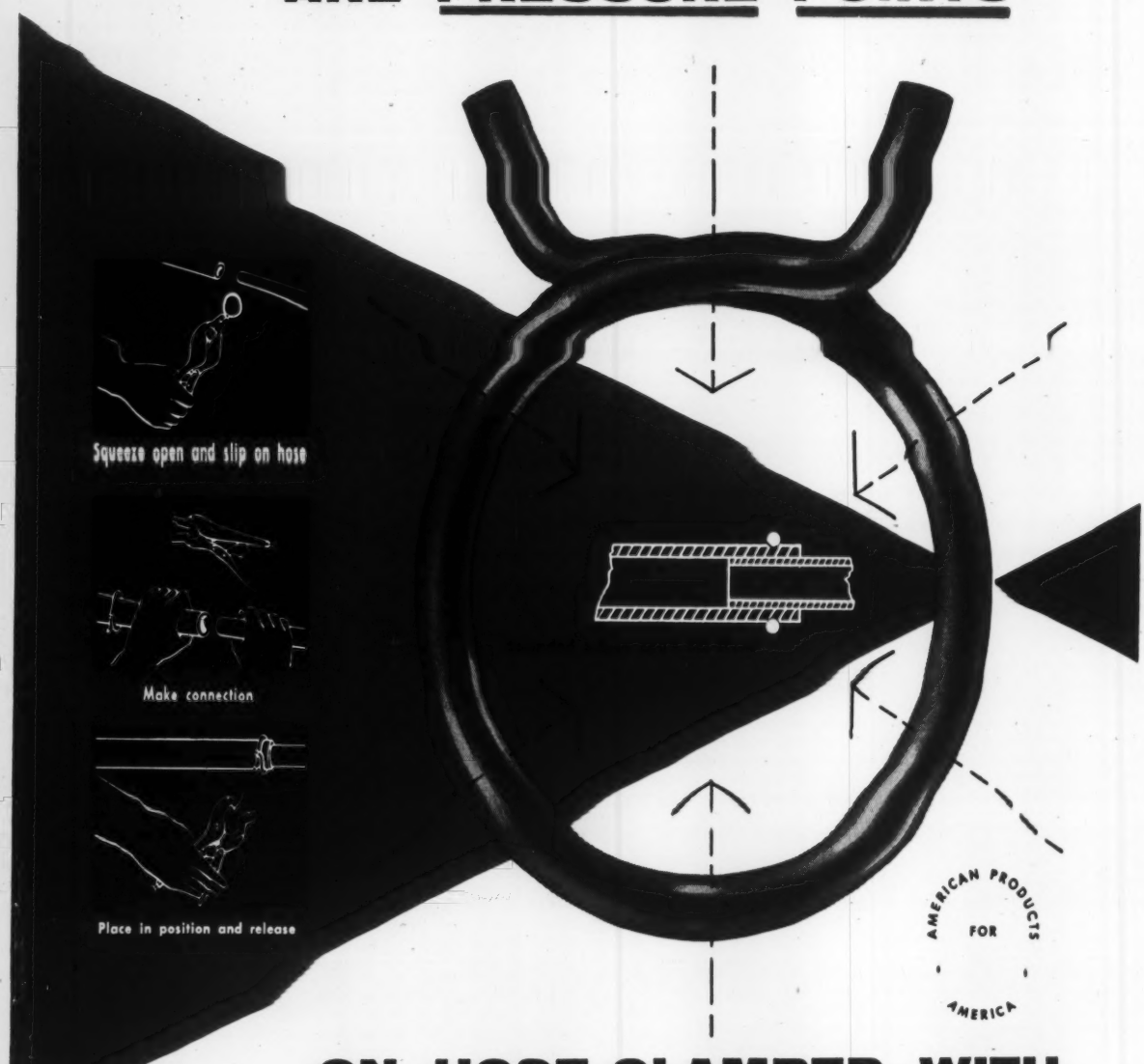


Investigate the Monsanto completely-balanced line of styrene plastic compounds developed for particular applications and sold under the trade name . . .

LUSTREX
Styrene Plastic

MONSANTO

ALL POINTS ARE PRESSURE POINTS



ON HOSE CLAMPED WITH EATON-RELIANCE HŎZ-FAS-NERS®

For tightly sealed hose connections with uniform, automatic pressure all the way around, it pays to investigate Eaton-Reliance Hoz-Fas-Ners.® Manufactured specifically for fastening rubber, plastic or fabric hoses, Hoz-Fas-Ners® speed up production, resist rust, eliminate the need for maintenance, and are re-usable.

Production men find hose fastening work considerably speeded up because of the one-piece design of Hoz-Fas-Ners® which permits ease of application in hard-to-get-at places.

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—ITEM 541—

For More Information Circle Item Number on Yellow Card—page 19

MACHINE DESIGN
June 28, 1956

Paper Work—Hindrance or Help?

HOW frequently one great inconsistency arises to plague engineering departments and their operations! Departmental systems and procedures are often hopelessly antiquated in relation to the fresh thinking and planning they are intended to implement. That bright new next year's model is being engineered and released to the plant with paper-work techniques designed or contrived in the year one of the company's chronology.

Inadequate part and drawing number systems, cumbersome drawing change forms and methods, hapless filing and distribution of drawings—all keep grinding along, with expediencies on the heels of exceptions. With patch upon patch, systems all too often get in the way of the job, instead of performing their mission of speeding and aiding the real work.

Frequently the problem is recognized, but there the thinking stops. The clean-up job looms like a monster, seemingly ready to consume a king-size portion of department time. And next year, with more designs, drawings, facilities, the job will look and be even bigger.

Fortitude to face the changeover sags still more when another observation is made. The cost of instituting new systems can often be appraised with dollar certainty, but money to be made or saved in the operation of the new systems can't often be stated with exactness. The proposal that promises future intangible gains runs the danger of being dismissed because recovery of inauguration costs appears to be a dubious gamble to the keeper of the budget.

But all of these negative things can be and have been said of many engineering programs themselves. And smart planning and common sense have more often than not converted question marks into profit dollar signs. The same kind of thinking and working applied to the engineering organization and its methods can produce comparable results—and pay off for a long, long time ahead.

Ben Hummel

ASSOCIATE MANAGING EDITOR

Here's a plan for an efficient, integrated system of

- Numbering parts
- Adopting parts standards
- Preparing drawings
- Preparing parts lists
- Distributing drawings
- Recording changes

The system is designed particularly for small and medium-size engineering departments, and may suggest worth-while procedures for departments of any size.

Simplifying

By John D. Kemper
Chief Mechanical Engineer
Telecomputing Corp.
Burbank, Calif.

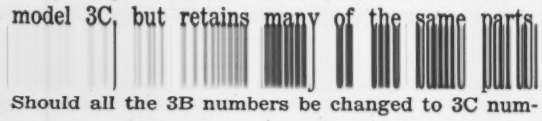
WHEN an organization is young and small, operations flow smoothly, with the boss himself exercising close personal control over everything. But often, after a half dozen or so men have joined the engineering staff, an ominous, disorganized pile of drawings and assorted notes begins to collect, and obtaining information from the files becomes increasingly difficult.

The problem of organizing information is approached with misgiving. Some sort of control obviously is required, but there is an understandable fear of the growth of a cumbersome system.

The system described here was developed in practice over a five-year period. Desirable features have been gleaned from more complicated procedures and tailored to the needs of the organization employing from 10 to 100 engineers and draftsmen. In a department of 25 or so, one clerk should be able to maintain the system.

Assigning Part Numbers: Often, when a part-number system is being designed, the first inclination is to impart special significance to a number, for example: to distinguish detail parts from assemblies, to signify location in the machine, to designate type of material, or to signify model and type number. These apparent conveniences should be avoided for a number of reasons.

A numbering system which includes a model designation in the part number (such as 3B431, meaning part 431 on model 3B) leads to an unfortunate situation if that part is ever to be used on another model. Immediately, the part number loses its model significance, or it must be changed to a new number. Both alternatives lead to ambiguity—the very evil a good system should avoid. Or, perhaps the model 3B is modernized to become model 3C, but retains many of the same parts.



Should all the 3B numbers be changed to 3C numbers? Assigning the part number only one duty in the first place—that of supplying the part with a unique identifying symbol—would have been better. A six-digit number serves very nicely and gives capacity for one million parts.

Blocks of numbers can be assigned to a given project or section of project for convenience in original selection of numbers. Sometimes the numbers which are easy to remember (such as 290000) are reserved for the important assemblies. Once assigned, however, the number is just an identification, regardless of where and how the part is used.

The most satisfactory operation will result from maintaining a single location for a part number assignment list or book. Duplicate lists, maintained at various locations for convenience, invite accidental duplication of a part number—and expensive correction of the error.

Interchangeability: The word *interchangeability* is a familiar one and generally implies that marvelous cornerstone of manufacturing which permits any part from the bin to fit and function satisfactorily. However, many pitfalls await those who fail to recognize the proper application of the principles of interchangeability to drawing and parts control. The rules are simply stated:

1. A part is interchangeable with another only if it fulfills the same function, attaches in the same manner, and occupies the same volume without interference with other parts.
2. Unless a part is altered so as to disturb its interchangeability, it always retains the same number.
3. If the interchangeability of a part is altered, it must receive a new number.

However, such things as appearance, material, finish, and fabrication procedure (i.e., a casting instead of a weldment) may, at times or by choice, be changed without disturbing interchangeability. Such changes are described by *change letters*, which will be discussed in this article, and the original part number is retained.

On the other hand, it is possible that a part may be altered so slightly as to require sensitive instruments to detect the difference and yet may

Engineering Controls

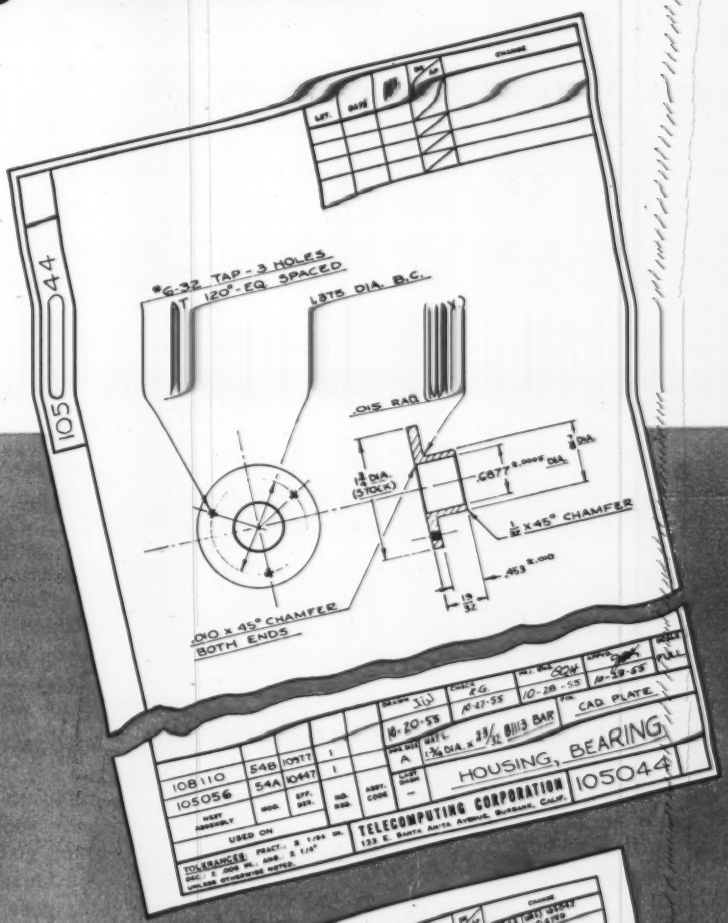


Fig. 1—Example of a detail part drawing. Callouts are all of the operation type. The "Used On" block indicates this is one of the components of assembly 105056 (Fig. 2).

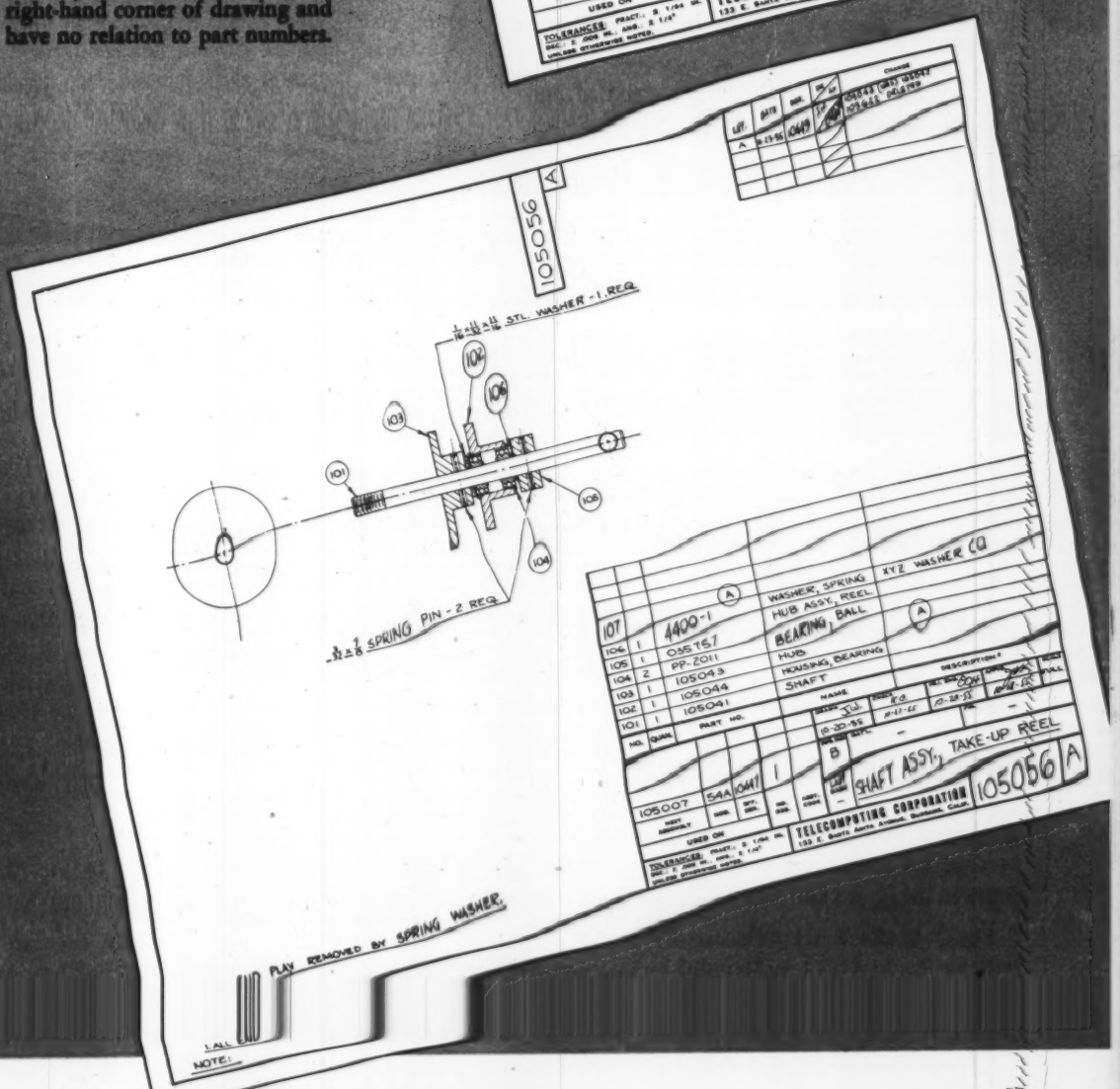

105056
.375 ± .015 ± .005 STL WASHER - 1 REQ.
.312 ± .005 SPRING PIN - 2 REQ.
PLAY REMOVED BY SPRING WASHER
NOTE: ALL END
SHAFT ASSY, TAKE-UP REEL
105056 A
TELECOMPUTING CORPORATION

Fig. 2—A simple assembly drawing. Encircled detail numbers refer only to information in lower right-hand corner of drawing and have no relation to part numbers.

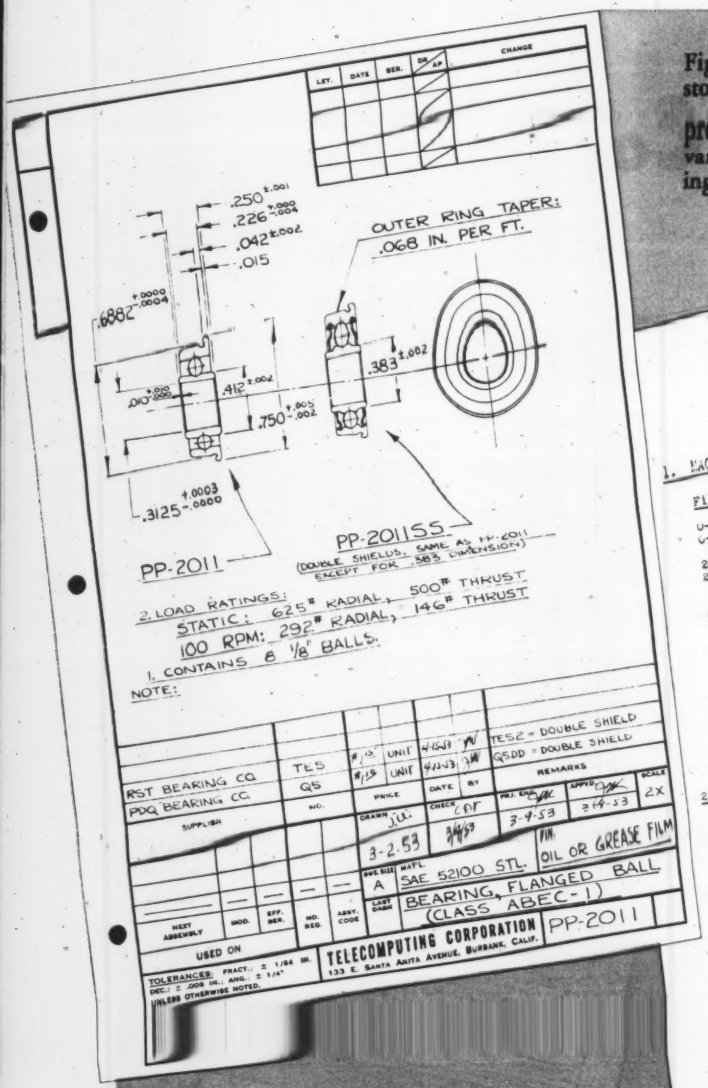


Fig. 3—A drawing from the standard purchased parts book. Two different manufacturers have been listed as acceptable sources for this part. Room has been provided for listing additional sources.

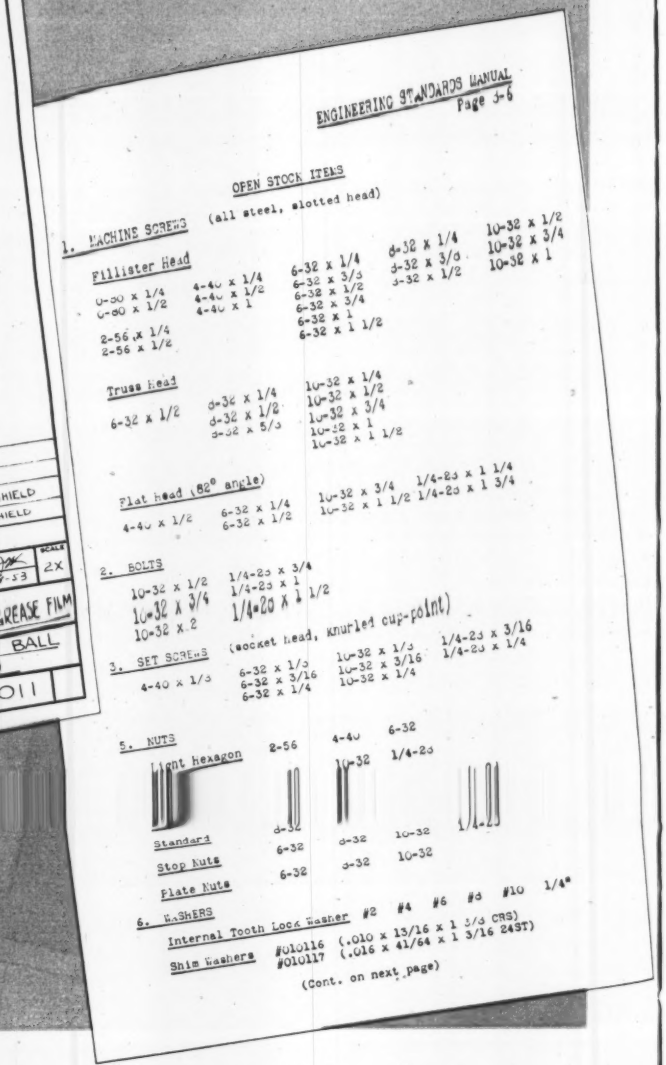


Fig. 4—A representative page from an open stock list. Use of the open stock philosophy prevents stocking of an unnecessarily large variety of items and eliminates frequent ordering of small quantities.

be noninterchangeable with the former part. Such a part receives a new number. Otherwise, the part number could not perform its duty of distinguishing between parts.

Callouts: A *callout* specifies requirements on a drawing, whether for a quantity of parts, or for a machining operation. The type of callout to be considered here is that type which determines assembly requirements.

Fig. 1 shows a detail part drawing. Note that the part number appears twice. The upper number facilitates locating the print in the file drawer.

The callouts are of the operation type, strictly for manufacturing instructions. This particular part is used on two different models. Information concerning the model and next assembly number appears in the "Used On" block.

Fig. 2 shows a simple assembly drawing. The part shown in Fig. 1 is included in this assembly along with certain other parts, some of which are purchased from outside vendors. Some of the parts are identified by encircled detail numbers, and some are not. Very few of the parts required are normally carried in stock and must be fabricated or purchased specially whenever a work order is released for a given quantity of machines. These are the parts which are given detail numbers, referring to the numbers in the parts list just above the title block. Most of the simpler parts, such as screws, nuts, and pins, are carried on hand in "open stock" and are not given detail numbers. These do not appear in the parts list. Thus, those parts listed in the tabular parts list are only those which must be specially made or purchased.

"Standard" Purchased Parts: In Fig. 2, some parts are seen to be those which are purchased from vendors' catalogs. Generally, they are specified by the vendor's name and number, as with detail 106. However, certain vendors' parts—ball

bearings, for example—may be specified repeatedly. Furthermore, many parts are made to industry-wide interchangeable specifications by many manufacturers. Such commonly used parts may be listed in a special loose-leaf book for ready reference and to provide a single number for use within the company. Also, many frequently used pieces of hardware for which catalog information is not complete with regard to dimension, etc., are conveniently included in this book for quick reference. Such a book might be called a "Standard Purchased Parts Book."

An advantage of following this system is that it permits the buyer to send a print of the part with his purchase order, thereby eliminating any doubt that could result from the description of the part. This advantage is especially helpful when a vendor's part numbering system is complicated, or when the vendor assigns an explicit number only upon receipt of a written description with the purchase order.

An example is detail 104, Fig. 2, bearing the number PP-2011. The "PP" stands for purchased part and is an integral part of the number. Fig. 3 is the corresponding drawing from the "Standard Purchased Parts Book." The tabular form above the title block is for data from acceptable manufacturers' catalogs for parts that meet the interchangeability requirements for this particular component.

A natural tendency on the part of the designers will be to select parts included in this book, thus eliminating helter-skelter choice from among numberless variations. Of course, an item should not be selected just because it is standard when the designer does not believe it is really the most satisfactory for the purpose.

The Open Stock Philosophy: No company can possibly anticipate its demands sufficiently to keep on hand adequate quantities of all parts that will ever be used. Thus, required purchased parts and material are ordered when a work order for a new group of machines is released. However, if only a few machines are built at a time, it appears uneconomical to buy such items as screws, nuts, and rivets in small lots each time a work order is released.

Generally speaking, it is possible to draw up a representative list of hardware parts, such as screws, nuts, washers, retaining rings, grommets, clamps, pins, collars, setscrews, rivets, and wire, which will cover most continuing requirements. Then, reasonably large quantities of these parts are purchased and maintained on hand in the stock room. Again, designers will tend to choose open stock items when possible, avoiding a haphazard selection of head styles, threads, etc.

A page from a typical open stock list is shown in Fig. 4. Such a list should be maintained in a drafting-room manual for ready reference. When use of a hardware item not on the list is necessary, such an item is called out like any other purchased part. New parts can be added to the list as desired, but the dangers of deleting a part should be self-evident, once that part has been considered open stock.

Parts Lists: After all the drawings on a project have been completed and released to the shop, the engineering department may feel that its responsibility has been discharged and that the task of building the machines is now the responsibility of the shop. However, it is usually difficult to gather the information necessary for effective parts control directly from the prints themselves. Larger organizations employ special departments to handle the manifold problems of control between engineering, manufacturing, and purchasing departments. In the small organization, the engi-

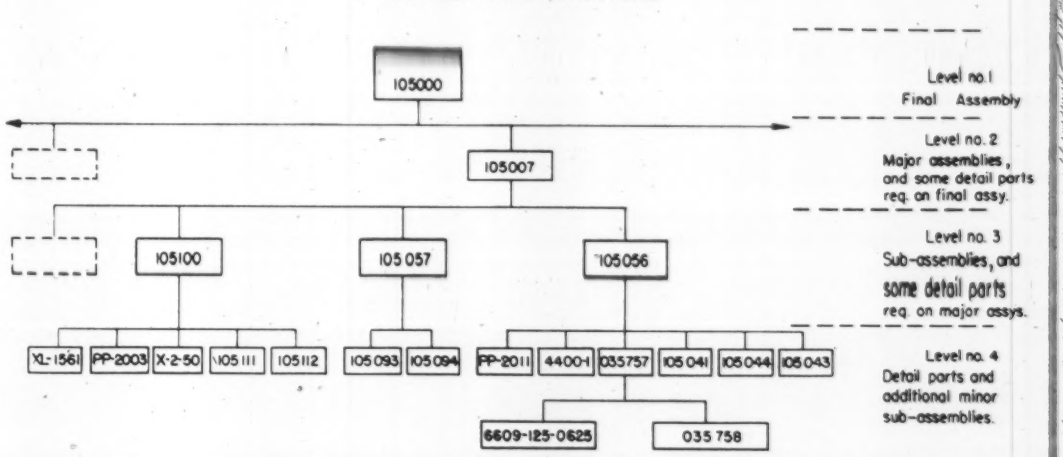
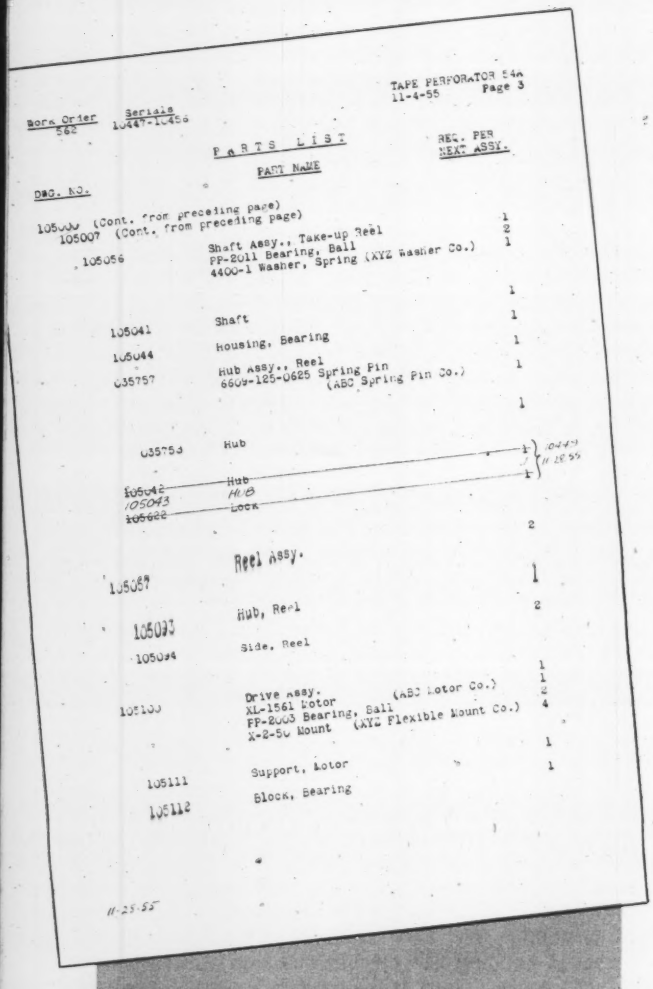


Fig. 5—Assembly 105056 (Fig. 2) shown in relationship to other parts and assemblies in the machine.



TAPE PERFORATOR 54A
11-4-55 Page 3

Work Order 563 Serials 1044?-1045?

PARTS LIST

DWG. NO.	PART NAME	REQ. PER NEXT ASSY.
105000	(Cont. from preceding page)	
105007	(Cont. from preceding page)	1
105056	Shaft Assy., Take-up Reel	2
	FP-2011 Bearing, Ball	1
	4400-1 Washer, Spring (XYZ Washer Co.)	
		1
105041	Shaft	1
105044	Housing, Bearing	1
035757	Hub Assy., Reel	1
	660W-125-0625 Spring Pin (ABC Spring Pin Co.)	
		1
035759	Hub	1
105042	Hub	1
105043	Hub	
105622	Lock	2
105087	Reel Assy.	1
105093	Hub, Reel	2
105094	Side, Reel	
		1
105100	Drive Assy. (ABC Motor Co.)	1
	XL-1561 Motor	2
	FP-2003 Bearing, Ball	4
	X-2-5C Mount (XYZ Flexible Mount Co.)	
		1
105111	Support, Motor	1
105112	Block, Bearing	

11-25-55

Fig. 6—A representative parts list, containing the same information as Fig. 5. Purchasing and production control departments can work directly from this list when a new group of machines is started through the plant.

neering department may be asked to assume this co-ordinating role in addition to that of designing the parts. An effective tool to this end is the *parts list*.

This list solves another problem that appears just as soon as a substantial number of prints collect. That problem is finding a particular print when the appearance and use of a part are known but not the number. Not knowing the number prevents looking it up in the file. One frequently employed method is starting at the front of the print drawer and looking until the right print is found. A much better way is to employ a parts list, which is a list of all the parts used on a given machine. Then looking up a number is facilitated by a knowledge of the unit on which the part is used, plus a knowledge of its relationship to other parts in the machine. Finding the part desired is accomplished by quickly scanning the parts list.

Figs. 5 and 6 show how to organize a parts list. The assembly of Fig. 2 (part 105056) is shown in Fig. 5, in relation to its components and to the assemblies up the line. Each part will fall on a given "level," dependent upon its remoteness from the final assembly, as diagrammed in Fig. 5. In an actual parts list, Fig. 6, levels are indicated by indentations. Thus, the parts list reveals immediately the relationships of the details and assemblies and other pertinent information. Notice that the number of parts required is for the next assembly. For example, in Fig. 6, there are $2 \times 2 = 4$ required of part 105094 on each major assembly part 105007.

The information needed to prepare the parts list is taken directly from the parts list block located above the title block on every assembly drawing. Since the parts list block does not include open stock parts, the parts list is a complete reference of all parts needed to make a machine except for those already on hand. Thus, the parts list can be used directly for preparation of shop work requests and purchase orders.

It should be noted at this point that the *drawing* is the source document. The parts list is primarily a recapitulation of the information shown on the assembly drawings, but organized in a more convenient fashion to serve the special purposes mentioned previously. However, the parts list does perform an original function all its own—it serves as the authority to use a certain group of prints

Table 1—Procedure for Releasing Drawings

New Drawings	Revised Drawings
1. Draftsman signs when complete and prepares drawing file card.	1. Draftsman changes vellum, and signs.
2. Checker reviews and signs when satisfied.	2. Checker reviews, withdraws drawing file card from file and attaches it to vellum.
3. Project engineer reviews steps 1 and 2, and signs.	3. Same as for new drawings.
4. Chief engineer, or his assistant, approves.	4. (Not necessary.)
5. Parts list and bill of material are prepared.	5. Parts list and bill of material are corrected, if necessary.
6. Release slip is prepared.	6. Same.
7. Prints of drawings and parts lists are released; release slip accompanies prints to destination, is signed in receipt for prints and is returned to the engineering department.	7. Same.
8. File card is placed in file; vellum is stored.	8. Same.

to manufacture assemblies with a given group of serial numbers.

The first serial number to which a drawing applies is shown in the "Used On" block on that drawing (serial number 10447 in Fig. 2). The first time a parts list is released, the appropriate work order and serial numbers to which that parts list applies is entered as shown at upper left in Fig. 6. As time passes, each new work order for which the same parts list applies is entered below earlier entries, and the list is re-released.

Parts lists should be released simultaneously with the drawings to which they refer. They are advantageously prepared on vellum, and released in the same manner as prints. Empty spaces are left for corrections. When a change in parts requirements, part number, etc., occurs, the change can be made by hand, and the effective serial number noted (Fig. 6, numbers 105042 and 105622). The date of changing the parts list is also noted, and the same date placed at the bottom of the sheet. That particular page is then re-released. If the parts list receives so many changes as to become confusing, it can be retyped and reissued, with appropriate changes in the serial number notation for which the new list is valid. This hand-correction procedure greatly simplifies and speeds up the handling of changes.

Bill of Materials: Since the parts list includes all the purchased parts, specifying the raw metal and other raw material remains. This may be done at least two ways:

Method 1: If large quantities or expensive materials are involved, all parts in a machine can be listed individually on a special bill of materials, with the material type and size entered from the material block on the drawing. The material specification on the drawings should already include adequate allowance for machining. Whenever a change affecting material occurs, the bill of materials page must be corrected and re-released.

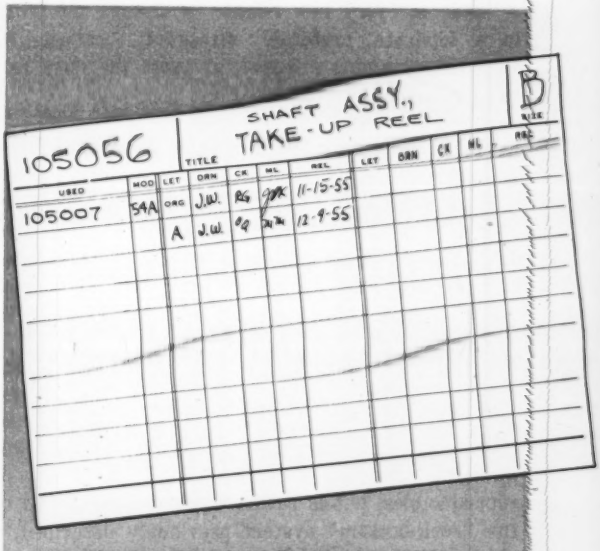
Method 2: If possible, all the short lengths of each type of raw stock required should be added up to provide a condensed list of the material required for one unit. Such a list should need revising only for major changes in the amount of material required; less important changes are ignored. Purchasing a small excess to absorb minor dimensional changes is customary.

Releasing Prints: A careful control of prints in circulation is required to prevent the use of obsolete information. A card, Fig. 7, is filled out and maintained in a file. When a drawing is processed for change, the card is withdrawn and goes with the drawing, to be initialed as each step in the procedure is completed, Table 1.

The back of the file card is a convenient place to record the various departments within the plant that possess prints of that particular drawing, and the quantity. Then, when a changed drawing is issued, the proper number of new prints can be sent to the appropriate departments. Department supervisors should make certain that the new prints are placed in circulation and the old prints destroyed. Each print should be stamped with the name of the department to which it is being sent. Every print which is not part of such a "living" file should be stamped "Reference Only," and should not be used for fabrication purposes.

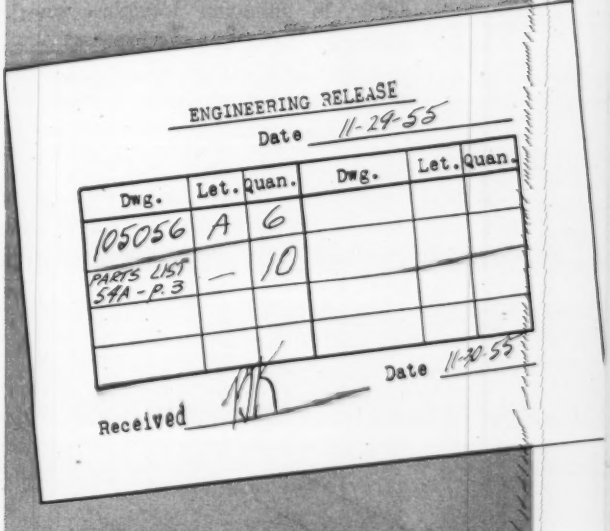
A *release slip,* Fig. 9, is filled out in duplicate before prints are made, as a control to be sure various release batches do not get mixed up or overlooked. The duplicate is retained by the engineering department, and the original accompanies the prints to their destination.

Keeping Up with Changes: Changes can swamp


105056 — SHAFT ASSY., TAKE-UP REEL — SIZE D

USED	MOD	LET	DRN	CK	ENG	REL	LET	DRN	CK	ENG	REL
105007	54A	ORG	J.W.	RG	[illegible]	11-15-55					
		A	J.W.	RG	[illegible]	12-9-55					

Fig. 7—Drawing file card, which accompanies drawing during release procedure, and then is filed as an index to vellum files.


ENGINEERING RELEASE

Date 11-29-55

Dwg.	Let.	Quan.	Dwg.	Let.	Quan.
105056	A	6			
PARTS LIST 54A - P. 3	—	10			

Received [signature] Date 11-30-55

Fig. 8—Release slip, which accompanies job (up to eight drawings and/or parts lists) through printing and delivery stages to ensure preparation of correct quantities of prints. It is filed temporarily as evidence of delivery.

an engineering department if they are not kept track of properly. Interchangeability must not be forgotten. If the revision causes noninterchangeability, a new drawing—with a new number—is prepared and released. This causes a change in the assembly drawing, which may or may not render *it* noninterchangeable. Proper attention here will prevent great confusion and costly straightening-out processes in all departments of the company.

The procedure is straightforward—the change is simply made on the original vellum and the new prints are issued, the changed print providing its own notice that a change has occurred. First, however, the most recent print is removed from the engineering file and placed in a permanent record file of superseded prints. Furthermore, in order to protect against fire loss, one extra print is made of every new release or change for filing in a separate, preferably fireproof, location. In case the originals are lost, at least the data can be recovered from the prints in this safe location. Satisfactory transparencies can be made from clear prints.

Many companies make a duplicate transparency of a vellum whenever a release occurs. The original is filed permanently, and the duplicate is used for print-making and is the one which receives any changes which occur. Then, at the time of the release of a change, a new duplicate transparency of the changed drawing is made and put into current usage, while the original of the *change* is filed permanently. This method produces a complete, permanently protected set of reproducibles, but is rather expensive compared to the "rock-bottom" system previously described.

When a change has been made, a *change letter* is placed in the change block along with a brief description of the change, as shown in the upper right-hand corner of drawing 105056, Fig. 2. Letters are chosen in sequence (skipping I and O), and never should be quoted as a portion of the part number.

If desired, a special form usually known as an *advance engineering change* can be employed to serve as a quickly prepared notice of change, pending drawing revision. The change can be described briefly on this form, in an "is" and "was" fashion, assigning the next change letter, and providing proper space for authorizing signatures. However, such a form should not be relied upon for permanent change information, since small sheets appended to prints are easily lost. The prints of the revised drawing itself should be issued as soon as possible.

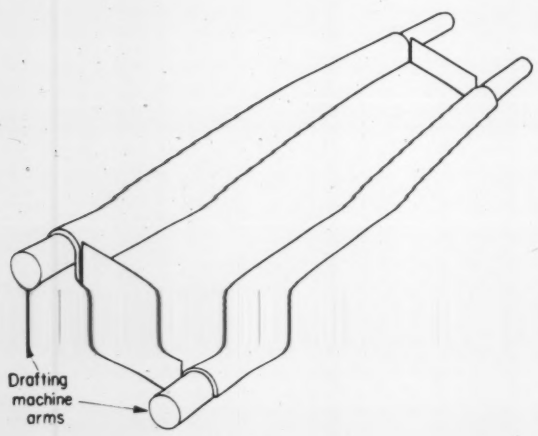
One more refinement is often useful. A form which provides engineering department approval for temporary deviations (such as material substitutions because of shortages or rework of scrap parts). Such a form might be called an *engineering order,* or a *drawing deviation authorization.* It is important to define clearly, preferably by a sketch, just what is being authorized and for what serial numbers the deviation is permitted.

Standards Manual: As soon as even a few procedures have been agreed upon, they should be written down and filed in a loose-leaf book. Memories are short, and the whole thought process must be repeated when problems recur, unless decisions regarding procedures were recorded. Such a collection may ultimately become a standards manual, but it can be kept in quite informal fashion pending preparation of a more formal manual.

Tips and Techniques

Drafting-Machine Gadget Tray

A simple tray to hold pencils, and other equipment can be made from a single piece of light-gage metal to fit certain types of drafting machines. Width must match machine arms; length, to suit requirements; depth, about ½-in. — BERTON J. LEAVITT, *Cushman Motor Works, Lincoln, Neb.*

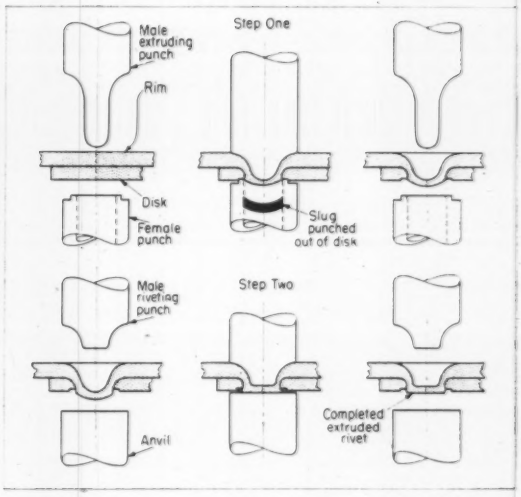


Cushioned Drawing-Board Pencil Holder

A COMBINATION cushion for the front edge of the drawing board, and a stop for holding pencils, instruments and sample parts, can be made from rubber strip. Use an extrusion or cut strip about 3 or 4 in. longer than the front edge of the board. Cement it to the front edge so that about ¼ to 5/16-in. sticks up above the board surface. Ends are carried around the front corners onto the sides of the board.—MORRIS O. MILLER, *Lawrence, Mass.*

Do you have a helpful tip or technique for our other readers? You'll receive ten dollars or more for each published contribution. Send a short description plus drawings, tables or photos to: Tips and Techniques Editor, MACHINE DESIGN, Penton Bldg., Cleveland 13, O.

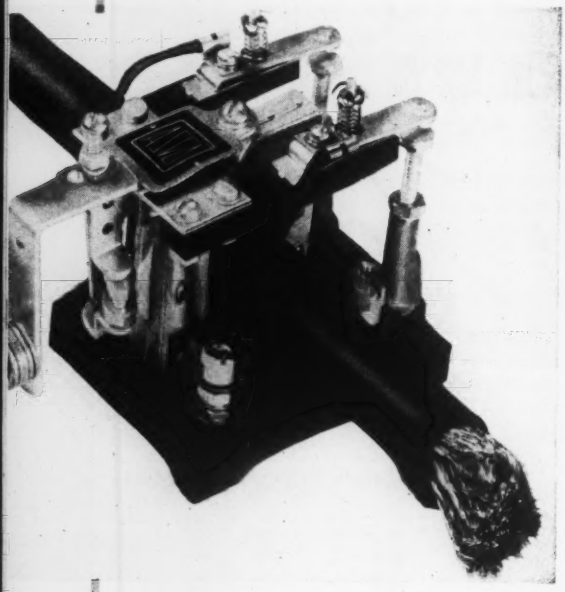
scanning the field for Ideas



EXTRUDED RIVET PROCESS provides leakproof fastening of metal parts assemblies. The riveting technique is employed by the Budd Co. in joining wheel rims and disks to produce an airtight construction for truck and passenger cars using tubeless tires.

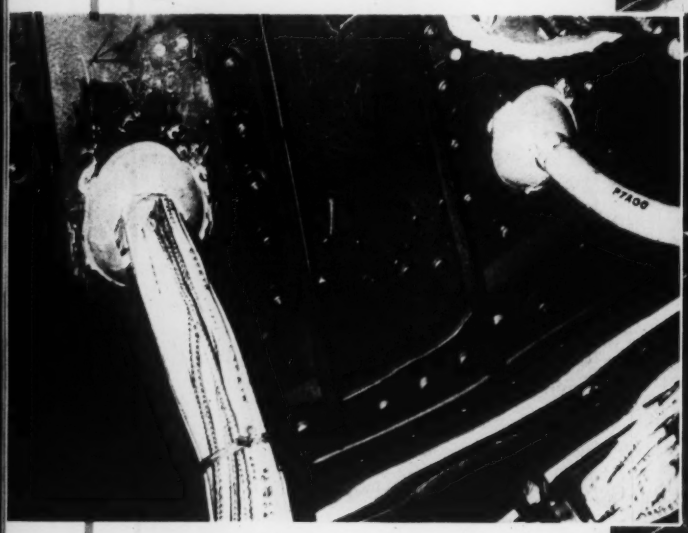
The first step in forming the extruded rivet is accomplished by forcing metal from the rim into a hole punched simultaneously into the disk. A second step finishes the riveting operation by press-fit locking the two pieces in a second punch and die set up. The rim surface remains unpierced and hence is airtight.

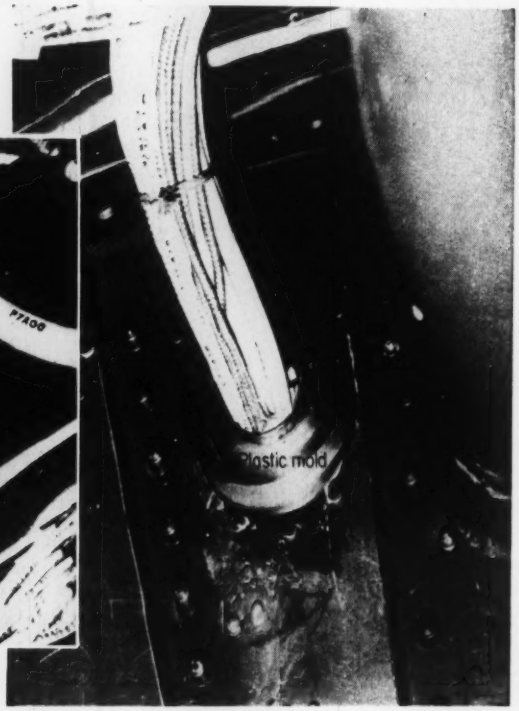
IDEAS



COILLESS RELAY construction functions like a current transformer. Developed by the Automatic Switch Co. for continuous welding machines, the relay is operated by the magnetic field produced by current flow in a load cable that passes through the relay assembly. In application, the design closes contacts automatically when a specific current value is reached.

MOLDED-IN-PLACE SEALS for electrical wiring cables and hydraulic lines passing into or through pressurized areas simplify assembly problems and offer cost advantages. The sealing method consists of passing wires, or tubing, through a bulkhead opening and then injecting Thiokol liquid polymer-based sealing compound into hemispherical plastic molds around the wires. This liquid compound converts entirely to a rubber at room temperature without shrinkage, providing an effective seal. The seals can be applied at any time during assembly or in the field. Developed at the Torrance facility of Douglas Aircraft Co., the technique has been employed in the F4D Skyray for hermetic sealing of electrical wiring systems and components.





Design and performance of the CYCLOID SPEED REDUCER

. . . a unique power-transmission concept

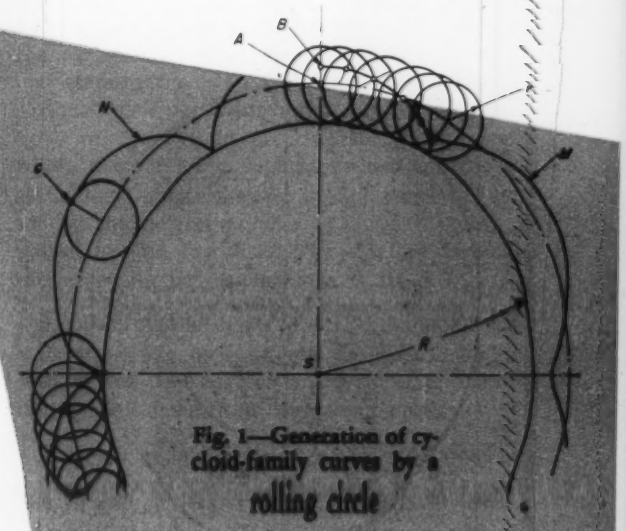


Fig. 1—Generation of cycloid-family curves by a rolling circle

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UNLIKE toothed gear-drive systems, the *cycloid speed reducer* transmits power without sliding motion between mating parts. Contact, instead, occurs with pure rolling motion. This feature accounts for the substantial performance benefits given by the cycloid drive within certain speed and power ratings. Theory and design details are presented in this article.

Geometric basis for the cycloid drive is one of the curves generated when one circle rolls around the periphery of another. In *Fig.* 1, point *C* is on the circumference of a generating circle with radius *r*. As this circle rolls around the base circle, point *C* traces curve *N*, the familiar epicycloid.

A point inside the generating circle, point *B*, traces the scalloped curve *M*, which is an *epitrochoid*. This curve—classed for easy reference as a member of the "cycloid" family—identifies the cycloid gear reducer and provides the geometric basis for its operation.

For each circuit of the generating circle around the base circle, *L* lobes are traced on curve *M*, where

$$L = \frac{R}{r} \qquad (1)$$

Radii of the generating circle and base circle are *r* and *R*, respectively.

If R/r is a whole number, curve *M* will be closed and continuous. Only a closed curve can be used in an actual cycloid mechanism.

As the generating circle rolls on the base circle, it performs two rotating motions: One around its center with angular velocity ω_1; the other around the center of the base circle with angular velocity

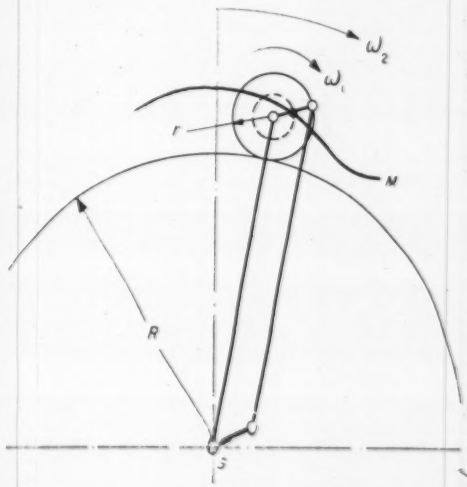


Fig. 2—Compound motion of generating circle illustrated by a four-bar linkage

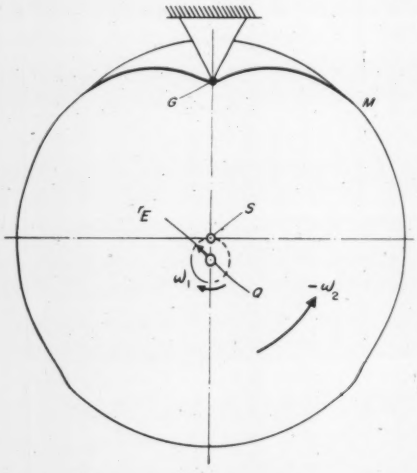


Fig. 3—Above—Epitrochoid curve traced on moving base circle by a fixed point

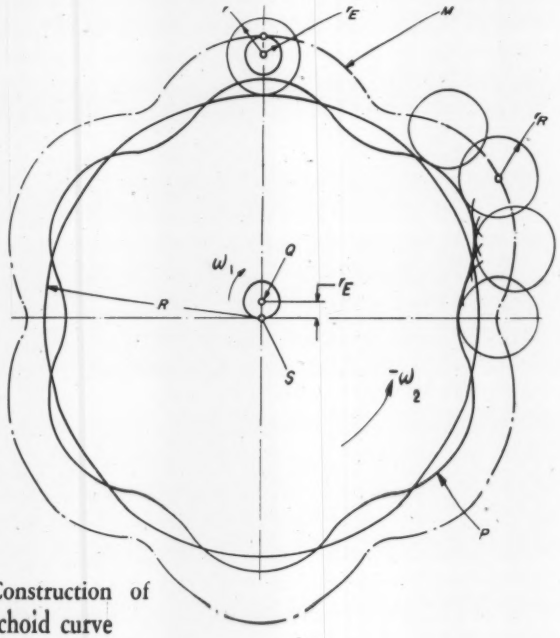
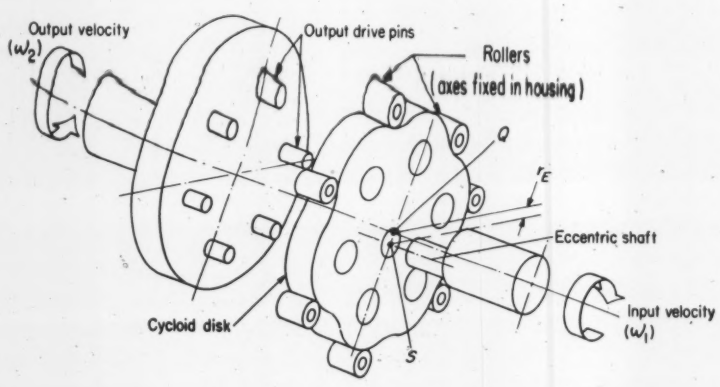


Fig. 4—Right—Construction of parallel epitrochoid curve



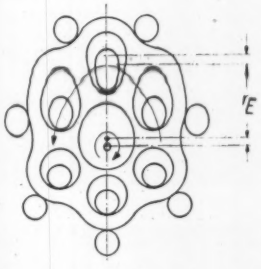


Fig. 5—Schematic of component arrangement for cycloid speed reducer

ω_2. This compound motion of the generating circle is illustrated by the four-bar linkage in *Fig.* 2. Assuming that rolling occurs without slip, the relationship between the two angular velocities is

$$\frac{\omega_1}{\omega_2} = \frac{R}{r} \qquad (2)$$

So far, the base circle has been held stationary. Assume, as in *Fig.* 3, that point *G* is fixed in space so as to trace a curve on a moving base circle. Let the base circle turn around its center with velocity $-\omega_2$ and, at the same time, let center *S* rotate eccentrically around point *Q* with velocity ω_1 and radius r_E. Point *G* traces the curve *M* as before, this time on the moving base circle. Consideration of the resultant velocity of the tracing motion shows the necessity for the negative sign on ω_2.

Curve *M* is shown in relation to its base circle in *Fig.* 4. Curve *P*, parallel to *M*, is drawn as the envelope of a number of construction circles of radius r_R with their centers on *M*. Operation of the cycloid speed reducer requires that disk P perform two "reverse" motions described in the discussion of *Fig.* 3. As the disk moves in this manner—that is, revolves around its center *S* while *S* moves eccentrically around point *Q*—its periphery always remains in contact with a roller like the one with radius r_R in *Fig.* 4.

Obviously, after each turn of the disk around *Q*, the same relationship of roller and curve lobe is established. This indicates that more than one roller can be arranged around the cycloid disk, all rollers going through the same cycle of contact, but at different successive times. The number of these rollers is equal to the number of full revolutions made by a roller as the disk turns once in its compound rotational cycle, or

$$N_R = \frac{R}{r} + 1 = \frac{\omega_1}{\omega_2} + 1 = L + 1 \qquad (3)$$

Because the cycloid drive in *Fig.* 4 has six lobes,

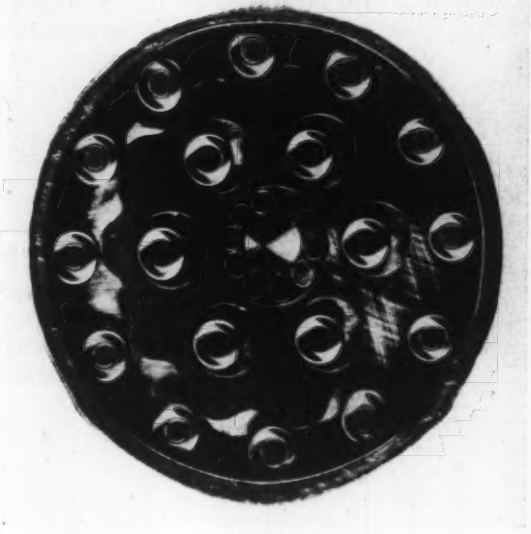


Fig. 6—Cycloid-drive model with 11:1 reduction ratio

that is $R/r = 6$, it will have seven rollers equally spaced around a circle of radius $R + r$ with center at point Q.

Mechanical components of a cycloid drive are a cycloid disk, an eccentric, and a number of rollers fixed in the housing. The eccentric rotates at input speed ω_1; all other rotations are at output speed $-\omega_2$. For each eccentric turn about Q, the cycloid disk is forced to advance one lobe by the rollers.

For pure rotational motion from the output shaft, the eccentric wobble of the disk must be filtered out. As shown in *Fig.* 5, this is accomplished by pins (or rollers) that mate with circular holes in the cycloid disk. Hole diameters exceed the pin diameters by $2r_E$.

Equations 1 and 2 prove that the reduction ratio ω_1/ω_2 of the cycloid drive must be an integral whole number. The highest reduction ratio per stage found practical so far is 85:1, which is a limit set by the largest number of lobes that can be spaced around the disk. The smallest reduction ratio for practical applications is about 7:1.

A model cycloid drive with 11:1 reduction ratio is shown in *Fig.* 6. Here, two eccentric disks have been spaced 180 degrees apart so as to improve the dynamic balance at high input speeds.

A cycloid reduction drive is shown in cross section in *Fig.* 7. Units of this type have been in operation for about 15 years. They run virtually without audible noise and with an efficiency of 98 to 99 per cent. There are no points of concentrated load combined with high sliding speeds, and cooling, therefore, is not required. Grease lubrication in completely enclosed housings is sufficient.

In *Fig.* 8, the mechanical components of a cycloid speed reducer with a built-in motor drive are shown.

Operating stresses in the cycloid drive are quite different from those in toothed gear systems. While gears operate with intricate combinations of bending stresses, surface compression stresses, and deflections which affect stress distributions, the chief concern with cycloid drives is almost exclusively surface compressive stresses. Load conditions are analogous to those in roller bearings or in freewheeling clutches.

Material for the rollers and cycloid disks is conventional ball bearing steel. Heat treatment

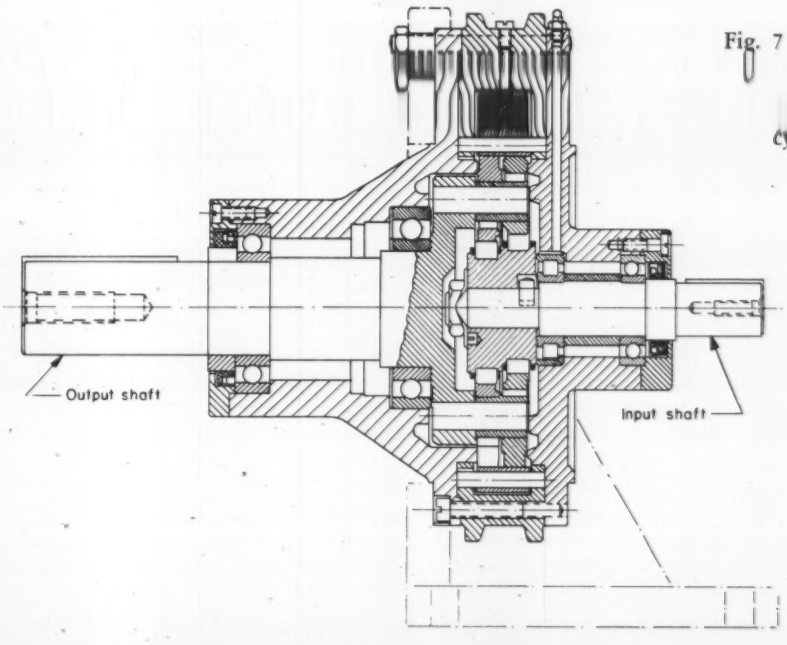


Fig. 7 — Single-stage cycloid unit

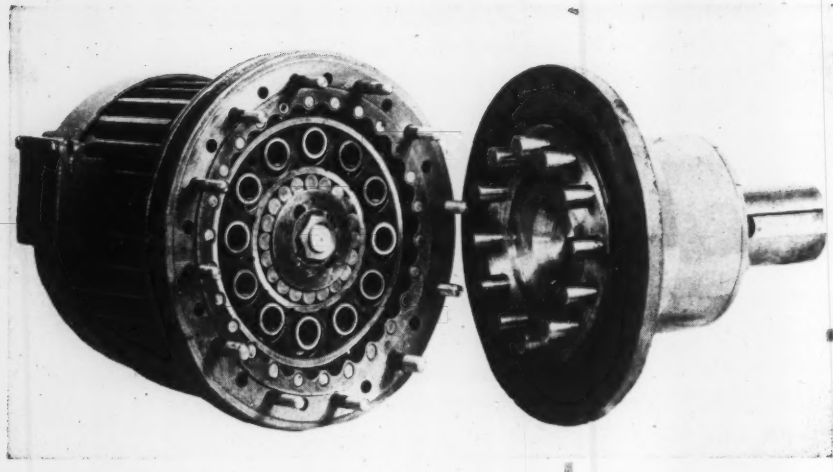
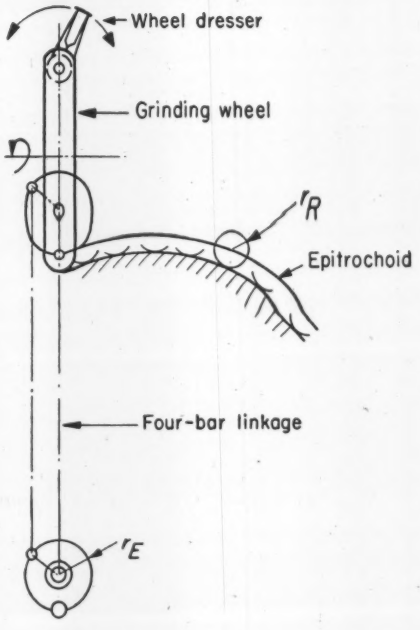


Fig. 8 — Mechanical components of cycloid reducer with integral motor

Fig. 9 — Method for grinding epitrochoid curve



CYCLOID SPEED REDUCER

includes through-hardening to Rockwell C64 hardness (minimum) and all final dimensions are obtained by grinding. This must be done with a degree of accuracy comparable to that of precision roller bearings in order to assure uniform load distribution. Calculation of stresses, dimensions and load ratings is based on the same considerations as used for roller bearings.

Manufacturing problems of cycloid units concern only the proper precision grinding of the cycloid parallel curves. The geometrically accurate shape must be generated by a suitable linkage that provides the two rotary motions outlined in the discussion of *Fig.* 3. Considerations of grinding wheel wear, compensation, dimension control, metallurgical requirements concerning prevention of grinding burns, and quality control apply in the same way as for other precision grinding work. A schematic of one possible method of cycloid grinding is shown in *Fig.* 9. Other arrangements have been developed, improving the production aspect of the grinding process and making the shape of the generated curve independent of the radius of the grinding wheel.

Comparison of four types of reduction gears is given in *Fig.* 10. Assumed reduction ratio for these drives is 75:1, power output is 25 hp, and input speed is 1000 rpm. Performance estimates for the toothed-gear units assume the use of high-quality industrial gears in continuous operation.

It should be noted that the 75:1 reduction ratio is particularly well suited to the cycloid drive, which produces it in one stage. The other systems, of course, have different ranges in which they operate most efficiently or where they are more practical from the design viewpoint.

Differential units can develop very high reduction ratios per stage, their operation being based on the difference in the number of teeth in two gears. Ratios of 50:1 to 100:1 are normal. Because of high internal power circulation, however, their efficiency is too low for practical speed reduction use.

Worm gear drives are best in the 10:1 to 50:1 range. They work with less noise than conventional gears and have better resistance to shock loads. Their efficiency ranges between 50 and 80 per cent. For the speed and power ratings in *Fig.* 10, a high-quality worm drive would have an efficiency of about 60 to 65 per cent. Losses are due principally to the high sliding velocities of the worm teeth, and the unit shown would require a heat exchanger to dissipate the generated heat. The right angle arrangement may be an advantage or a drawback, depending on the application. The input speed of 1000 rpm is near the upper practical limit for the worm drive.

Conventional gear units will generally require three stages to obtain the 75:1 ratio. Pinion diameters are determined by the permissible tooth loads and the desired ratio is obtained by selection of appropriate gear diameters. Since the gears are relatively large, overall housing dimensions are substantial. Efficiency of conventional gearing is high compared to worm drives; losses are due principally to sliding friction at the tooth flanks.

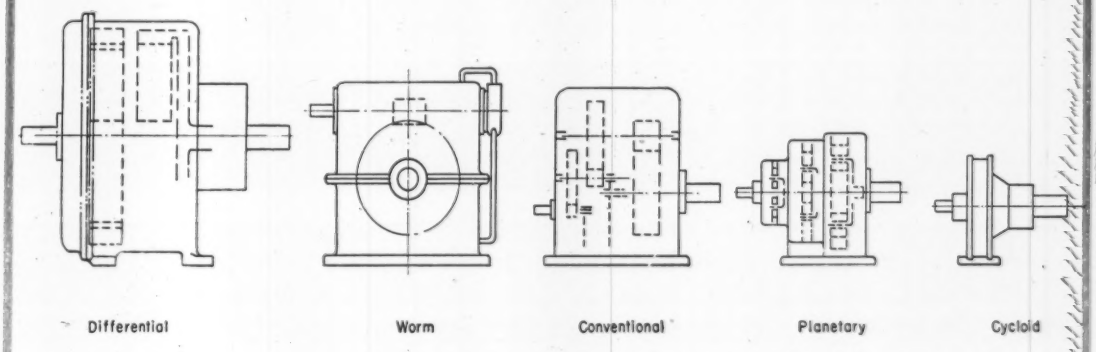


Fig. 10—Comparison of four reduction units with 75:1 speed ratio. Rated horsepower = 25; input speed = 1000 rpm

Sliding velocities, however, are substantially lower than on worm drives. Thus a conventional gear drive of good quality will have only about 1 per cent power loss per stage. Uniformity of motion ("smoothness"), noise level and shock resistance are generally not as good as for worm drives. The conventional drive usually has offset parallel shafts, although in-line shafts are possible for multiple stage units. Concerning speed limitations, the conventional gear has gone through a long history of design improvement, and input speeds of 12,000 rpm and higher are in practical use. This makes it the natural choice for use with high-speed prime movers.

The planetary unit is more compact, but will usually require three stages for a 75:1 ratio. Its performance is comparable to that of conventional units; efficiency may be slightly lower, but still very high. Its compactness is a major advantage.

The cycloid unit can easily provide the 75:1 ratio in one stage. Its arrangement is compact and concentric, and its high efficiency is due to absence of sliding contact between the power-transmitting parts. Input speeds to 3000 rpm have been tested successfully so far. The unit used here for comparison is based on an actual reduction gear, now in quantity production.

Application of cycloid units is indicated where high reduction ratios are required in the medium speed and power range. To date, service experience exists for cycloid drives to 50 hp with input speeds of about 1200 rpm and reduction ratios to 85:1 in one stage. Smaller units have been built in the fractional-horsepower range, with input speeds to 3000 rpm. Because it operates with pure rolling contact, the cycloid drive is never self-locking, and it can therefore be used for speed increasing applications. Reduction ratios depend on the number of lobes on the cycloid disk. This limits the reduction (or step-up) ratio to integral numbers, unlike conventional gear drives which can provide almost any desired ratio. For large ratios, two or three stages may be combined, giving ratios up to 5000:1.

ACKNOWLEDGEMENT

The authors are indebted to Cyclo Getriebebau, GMBH. Germany for material presented in *Figs.* 6, 7, and 8.

Tips and Techniques

Working on the Reverse Side of Drawings

PUTTING lines on the back of a drawing on tracing cloth, paper or vellum has certain advantages.

A line on the back reproduces very well, because it is closer to the photosensitive paper. Also, such a line can be readily erased without disturbing work on the front of the paper; or the front can be erased without disturbing lines on the back.

One use of this method is to draw boxes on the back for tabulation of dimensions and data that is lettered lightly on the front. Prints or a reproduction master may then be made. The lettering on the original may be erased without disturbing the ruling on the back, and a new set of data added.

One application of this technique might be for dimensioned outlines of a series of similar assemblies of various sizes.

Cross-section lines for plotting charts and graphs may be ruled on the back and the curves put on the front. The lines on the front may be erased or changed without affecting the grid. Guide lines for lettering may be drawn in the same fashion.—W. GOVAN, *Cooper Union, New York, N. Y.*

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DESIGNING ELECTRONIC EQUIPMENT

FOR MAINTAINABILITY *(Second of a Series)*

Basic design recommendations for separating electronic equipment into

By John D. Folley Jr. and James W. Altman

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Pittsburgh

IF ELECTRONIC equipment is relatively large in size and weight, it is often advantageous from a maintenance standpoint to design the equipment with small removable or replaceable units. There are two primary reasons for building electronic equipment in such a manner.

First of all, constructing electronic equipment in units that, in turn, may contain assemblies, subassemblies and parts, permits division of maintenance responsibility—particularly trouble shooting—among various maintenance levels. For example, equipment may be designed with customer-maintained units that are in turn divided into field-serviced units. The units designed to be field serviced can be divided into factory-serviced units. This design approach permits rapid corrective maintenance at the customer level with additional maintenance at other levels.

Secondly, when equipment is built with removable units, assemblies, etc., it is obviously much easier and faster to work on malfunctioning parts.

Maintenance Levels and Procedures: There is a definite relationship among unit design, maintenance levels, and maintenance procedures. For example, if maintenance procedures specify that a particular unit in a piece of electronic equipment should be brought to a service shop if it contains *any* malfunction, there is little point in designing the unit to contain assemblies that are removable by the customer.

The design schedule for maintainability discussed in a previous article (MACHINE DESIGN, June 14, 1956) suggested some of the considerations for integrating the design of units with maintenance procedures for each maintenance level. Only through such an integrated design procedure can equipment be designed with units that will be most effective for maintenance. For example, the design of two similar major components or units should probably differ appreciably if maintenance procedures specify that one is customer replaceable and the other is not replaced at the customer level but contains a number of customer-replaceable assemblies.

Relationships Between Units: The number of inputs to and outputs from each unit at each maintenance level should be minimized. This can be done by grouping circuits so that a minimum criss-crossing of signals between units is required.

No unit should have more than about 30 v applied to it (for heater or standby power) when the main power switch for the equipment is turned off.

Units should not be "married" to each other. It should be possible to check and adjust each unit separately, and then connect the units together into a total functioning system with little or no additional adjusting required.

Overload indicators should be provided on each major unit even if it is sometimes desirable to keep overloaded circuits in operation.

Interchangeability of Components: Regularly stocked parts should be used in design where it is feasible. Where practical, assemblies, subassemblies, and parts should be interchangeable within and between different equipment units. Naturally, interchangeability of components reduces supply problems.

The number of different sizes and types of screws and quick connectors used on equipment should be kept to a minimum.

Labeling: All units and parts should be labeled with full identifying information. The outside covering of manufactured parts, such as resistors,

Units, Assemblies and Subassemblies

The value of designing maintainability into electronic equipment cannot be overemphasized. This article contains several valuable recommendations for designing electronic equipment units, assemblies and subassemblies. The manner in which an equipment is subdivided will determine to a large extent the degree to which total maintenance responsibility can be assigned to different maintenance levels. It also affects markedly the ease of maintenance at each level.

condensers, and tubes, should be stamped with relevant information concerning electrical characteristics of the part, when feasible. Direct presentation of this information makes interpretation much easier than color coding.

Each terminal should be labeled with the same code symbol as the wire to be attached to it.

Labels should be etched or embossed into the component or chassis rather than merely painted or stamped on the surface. If surface labels must be used, decals or stamped labels are preferable to stenciled labels because they are usually easier to read.

Labels should not be hidden by units and parts. For example, labels stamped on the chassis should not be placed under the parts that they identify.

Color Coding: An effective mode of identifying parts or presenting other information is color coding.[1,2] This is true, however, only when the coding is unambiguous. The meaning of colors should be explicitly stated in printed job instructions and/or on a panel of the equipment that employs color coding.

The meaning of a particular color should be consistent throughout a prime equipment and its maintenance supports. It should also be consistent for other equipment insofar as possible. Most important, too, colors should not wear off or fade.

Colors of Indicator Lights: Only three colors of coded signal lights, e.g., panel lights on testers, are recommended if color-defective technicians will use them. These are bright and highly saturated red, green and blue. Don't use white or yellow with the above colors because color-defective technicians may confuse red with yellow and green with white.

[1]References are tabulated at end of article.

Colors of Equipment: Surfaces painted with the colors listed below will be clearly distinguishable from each other:

Red	1110	Blue	10B 7/6	White	1735
Orange	1210	Purple	2715	Black	1770
Yellow	1310	Gray	1625	Buff	1745

The preceding numbers refer to colors for ready-mixed paints[3] with the exception of blue which follows the Munsell system.[4]

Black, white, yellow, and blue are easily distinguishable by most persons—even those with defective color vision. About 6 per cent of the male population has defective color vision.

If more than four colors are required in a piece of equipment, the other colors listed in the preceding table are best even for persons with defective color vision.

Do not use more than the nine different colors suggested on any one equipment. This number will usually be more than enough to differentiate parts of the equipment. However, if more colors are necessary, use check patterns of contrasting colors rather than solid intermediate colors. Some combinations of contrasting colors are black and white, red and white, black and bright yellow, and blue and bright yellow.

Mounting Bolts and Fasteners: For assemblies

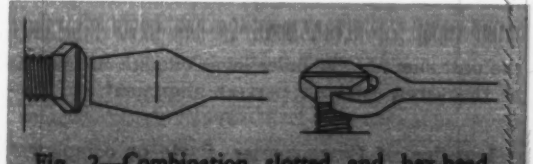

Fig. 2—Combination slotted and hex-head mounting bolts. Design allows use of screwdriver under normal conditions, but permits use of a wrench for jammed bolts.

and subassemblies, fasteners should fasten or unfasten with no more than one complete turn. Fasteners should never require nonstandard tools for operation. Hand-operated fasteners are even better.

Use combination-head mounting bolts with a deep internal-slot arrangement and hex head, Fig. 1. This type of screw can be operated with a standard screwdriver, but a wrench can be used on jammed bolts.

Always provide an external-grip head on bolts requiring high torques. This will reduce the need to drill out bolts with damaged slots. Even the use of round fillister heads permits a grip with a vise pliers if the slot is damaged.

Make mounting bolts semipermanently captive. Snap-on collars are good for this purpose, and permit easy replacement of damaged bolts.

Mounting bolts and fasteners should be clearly labeled as such. An "M" embossed on the top of the head would be useful if the practice could be widely used. Coloring them a distinctive color such as red makes location easy.

Use a rust and damage-resistant material for mounting bolts and fasteners.

Mounting screws should be interchangeable whenever feasible. Use as few different sizes as practicable.

Place heads of mounting bolts and fasteners on a surface adjacent to the technician's work space, Fig. 2.

Mounting and Assembling Provisions: Field-replaceable assemblies and subassemblies should be plug-in rather than solder connected wherever feasible. This is true of large assemblies and small subassemblies, such as electrolytic condensers, relays, and miniaturized throwaway circuits.

No more than four screws should be used for mounting a major unit in an installation unless stress considerations require more.

Assemblies and units should be replaceable with nothing more than common hand tools.

Units that must frequently be pulled out of their normally installed position for checking should be mounted on roll-out racks, slides, or hinges.

Always provide guide pins on units and subassemblies for alignment during mounting, Fig. 2.

Always provide limit stops on roll-out racks and drawers to prevent their being dropped. It should be possible to override these limit stops easily for replacement of racks and drawers.

Mount units and assemblies so that replacing one unit does not require removal of other units for access.

Covers or shields through which mounting screws must pass for attachment to the basic chassis of the unit should have holes large enough for passage of the screw without perfect alignment.

Location of Components: Parts or components within units should be mounted in an orderly array on a "two-dimensional" surface, and not "stacked" one on another.

Orderly layout is helped by mounting parts to one side of a board and wiring to the other side, with electrical contacts inserted through the board. This recommendation applies to both printed and soldered type circuits.

Locate parts so that large manufactured parts such as indicator and magnetron tubes that are difficult to remove do not prevent access to them.

Components should be placed so that:

1. There is sufficient space to use test probes, soldering irons, and other required tools without difficulty.
2. Tubes can be replaced without removing assemblies and subassemblies.
3. Resistors, capacitors, wiring, etc., do not interfere with tube replacement.
4. Structural members of units do not prevent access to components.
5. All throwaway assemblies or parts are accessible without removal of other components.

If customer-maintenance procedures require tube replacement, it should not be necessary to remove units from their installation to make such replacements.

Locate all fuses so that they can be seen and replaced without removing any other parts or subassemblies. Tools should not be required for replacing fuses.

Delicate components should be located where they will not be damaged while the unit is being

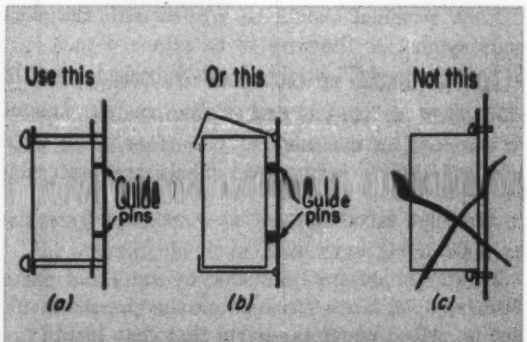

Fig. 2—Units fastened from the front for easy accessibility shown in *a* and *b* whereas design in sketch *c* is difficult to remove. Guide pins aid in alignment during mounting.

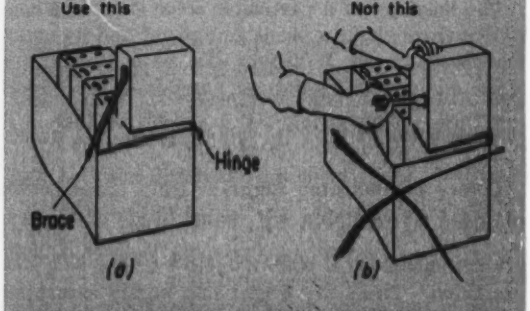

Fig. 3—Method of bracing hinged assemblies and subassemblies during servicing, *a*. Without a brace such units must be hand-held, *b*.

worked on. For example, do not position resistor boards where an operator or technician is likely to strike them with his hand or arm when making adjustments.

Internal controls such as switches and adjustment screws should not be located close to dangerous voltages.

Do not locate components that retain heat or electrical potential after equipment is turned off where technicians are likely to touch them while changing commonly malfunctioning parts.

Orient all miniature-tube sockets with the gap facing in one direction to help in replacing tubes.

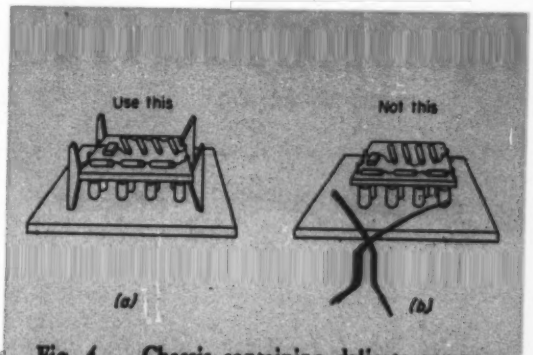

Fig. 4 — Chassis containing delicate components designed with rests or stands, *a*, is preferable to the design shown in *b*.

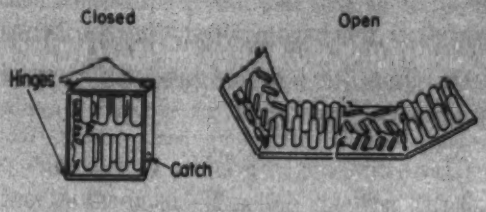

Fig. 5—Fold-out construction of subassemblies for easy accessibility. Parts and wiring must be carefully positioned to prevent damage to components.

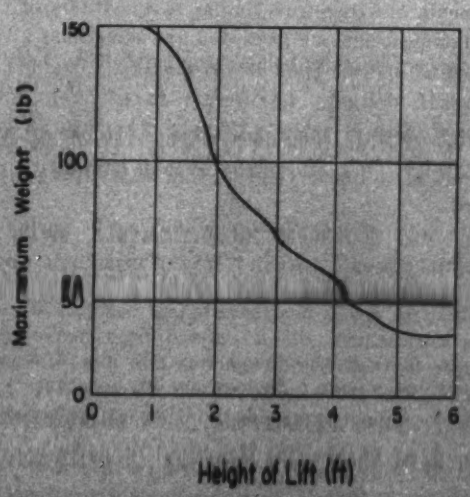

Fig. 6—Chart of absolute maximum weight-lifting capacity that can be expected of 95 per cent of technicians. Information supplied by Anthropology Section, Biophysics Branch, Aero-Medical Lab., Wright Air Development Center. Data are from tests run on 19 male subjects whose ages averaged 21.6 yr, weights averaged 161.2 lb, heights averaged 69.5 in.

Structure of Units and Assemblies: Only interconnecting wiring and structural members should be permanently attached to the unit chassis. All parts, such as, resistors, condensers, tube sockets, etc., should be mounted on subassemblies; otherwise, much of the value of designing equipment in units is lost.

Assemblies and subassemblies that are hinge-mounted to major units should have a brace or other provision to hold them in the "out" position during servicing, Fig. 3.

Units or assemblies should be designed so that delicate components are not required to support the chassis during repair of a malfunction. Rests or stands that are a part of the basic chassis should be provided whenever possible, Fig. 4.

Provide fold-out construction of subassemblies whenever feasible, Fig. 5. Position parts and wiring to prevent damage to them from opening and closing the assembly.

Make stress members of units strong enough to withstand the usual blows they may be expected to encounter in handling and transportation for maintenance.

Units should be small and light enough for one man to carry and handle if this arrangement is technically possible. The weight-lifting capacity of 19 male subjects whose ages averaged 21.6 years is depicted in Fig. 6. These weights are absolute maximums for lifting a unit of convenient size and shape with unlimited work space. Electronic equipment units should be designed for smaller weights to account for realistic work conditions.

Units should be designed so that individuals handling them are protected from sharp edges, points, heat, and electrical charges.

Irregular extensions, such as bolts, cables, wave guides, and hoses, should be easily removable before the unit is handled. Such protrusions are easily damaged and make handling of the unit awkward.

Other Mechanical Factors: Maintenance is usually easier when a whole unit is pressurized rather than a circuit or portion of a circuit running through a unit.

Units containing mechanical components, such as gear trains, should have provision for lubrication without disassembly or should not require lubrication by using sealed-in designs.

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Fig. 1—Any servo element may be represented by a box having an input, $x(t)$, and output $y(t)$.

A basic outline of Servo Mathematics

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IN A PREVIOUS article the closed-loop principle of control was established and it was shown from purely static or steady-state considerations how the steady-state accuracy of the system is much superior to that of an open-loop system. As pointed out then, however, the performance of a control system cannot be assessed on static considerations alone. The dynamic characteristics of the system components must be considered.

A comprehensive investigation of control system performance requires a knowledge of certain mathematical techniques, based on differential equation analysis. These techniques are summarized in the present article. Space limitations prevent a rigorous treatment. More thorough discussion is provided by the texts in the bibliography.

Input-Output Relationships: A servo system can be represented as a sequence of elements in a block diagram. Each element has an input and an output. Thus, in Fig. 1 $x(t)$ is the input and $y(t)$ is the output. If the relationship between them is of the form $y = kx$ then at any time the relationship between x and y can be represented as a straight line, Fig. 2*a*. This is called a linear relationship, whereas $y = kx^3$ is a nonlinear relationship. Here the relationship gives a curved graph, Fig. 2*b*.

Linear or proportional relations lead to differential equations which can be handled in a methodical and often simple manner. On the other hand nonlinear relationships lead to equations which are difficult, if not impossible to solve. The general theory of control deals with linear systems. No general method of approach exists for nonlinear servos, although considerable attention is being given to certain types of nonlinear systems.

In general an element having an input $x(t)$ and an output $y(t)$, both varying with time t, will be related by an equation involving their derivatives as well as x and y themselves. Once again linearity implies proportionality between effects. Thus for a simple mechanical network, Fig. 3,

$$m\frac{d^2y}{dt^2} + f\frac{dy}{dt} + ky = f\frac{dx}{dt} + kx \qquad (1)$$

This is a linear differential equation with constant coefficients.

For any given input, the output will depend only on the coefficients, such as m, f and k in Equation 1. Thus the element can be thought of as operating on the input to give the output. Servo elements are therefore similar to the filters of the communications engineer, and are sometimes given the same name. They are also called *transfer elements*.

The general relation between the input and output of a linear element can be written in the form

$$(a_n D^n + a_{n-1} D^{n-1} + \ldots + a_1 D + a_0)\, y = b_m D^m + \ldots + b_1 D + b_0)\, x \qquad (2)$$

where D is a shorthand notation for d/dt and where the a and b factors are all constant.

Any element governed by such an equation is said to be linear. One important property of such elements is that if an input x_1 causes an output y_1, and input x_2 causes an output y_2, then an input $(c_1x_1 + c_2x_2)$ causes an output $(c_1y_1 + c_2y_2)$, where c_1 and c_2 are constants.

This is known as *linear superposition*. It is sometimes given as the definition of a linear system, but since it holds good even if the constants are functions of time, it is not sufficiently precise in this instance.

A satisfactory definition of a linear system is

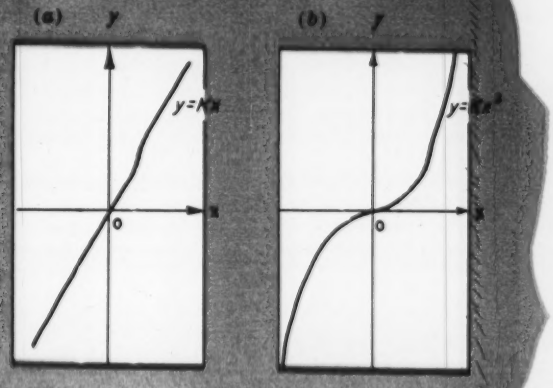


Fig. 2—Relationship of input and output of a servo element may be linear, *a*, or nonlinear, *b*. General servo theory deals with linear systems.

. . . techniques essential to methodical analysis of dynamic performance of closed-loop control systems

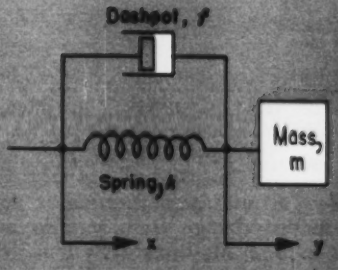


Fig. 3—In this simple mechanical network the output for a given input depends only upon mass *m*, damping *f*, and spring constant *k*.

that it is one which under steady conditions gives a sinusoidal output for a sinusoidal input of the same period. Although this is not a mathematically precise definition, it permits treating certain nonlinear elements as linear ones when a sinusoidal input causes an output which, although not sinusoidal, is periodic and of the same frequency as the input. Then only the first harmonic of the output is considered. The justification for this lies only in the accuracy of the results it yields.

If the input $x(t)$ is known, then the right-hand side of Equation 2 is a known function of time, say $f(t)$. Then the output can be obtained by solving

$$(a_n D^n + \ldots + a_1 D + a_0)\, y = f(t) \qquad (3)$$

To do this either the so-called classical or operational methods of differential equation analysis may be used. Of these the latter is quicker and far more suited to servo work.

Laplace Transformation: Probably the best known and most useful form of operational calculus is Laplace transformation. Even in moderately experienced hands Laplace transforms are powerful tools for solving differential equations. Briefly, Laplace transformation turns a differential equation in which the variables are functions of time, *t*, into an algebraic equation in which the variables are functions of a new variable, *s*, called the Laplace Operator.

Before a Laplace transform is defined, two functions which will be of interest might first be considered:

1. Unit Step Function. This represents a sudden change from zero to one at time $t = 0$, Fig. 4*a*. In order for this function to be amenable to the mathematical rules of differentiation and integration, it is defined as the limit of a continu-

Nomenclature

A_n = Residues of partial fraction expansion of $Y_c(s)$
a, b, c = Constants
D = Differential operator, d/dt
e_s = Steady-state position error
f = Damping constant of mechanical system
$F(s)$ = Laplace transformation of $f(t)$
$f(t)$ = Arbitrary function of time
h_n = Roots of characteristic equation
j = Square root of -1
K = Scalar gain constant
k = Spring constant of mechanical system
m = Mass constant of mechanical system
r = Order of servo
s = Laplace operator
T = Time constant
T_b = Buildup time
T_d = Decay time
t = Time variable
$U(t)$ = Unit step function
$W(t)$ = Weighting function of servo
x = Input to transfer element
$Y_c(j\omega)$ = Overall harmonic response function $= Me^{j\phi}$
$Y_c(s)$ = Overall transfer function of servo
$Y_o(j\omega)$ = Loop harmonic response function $= Ne^{j\psi}$
$Y(s)$ = Transfer function of element
$Y_o(s)$ = Loop transfer function of servo
y = Output of transfer element
$\delta(t)$ = Unit impulse function
$\Omega = 0.01\,\omega$
ω = Angular frequency, rad per sec

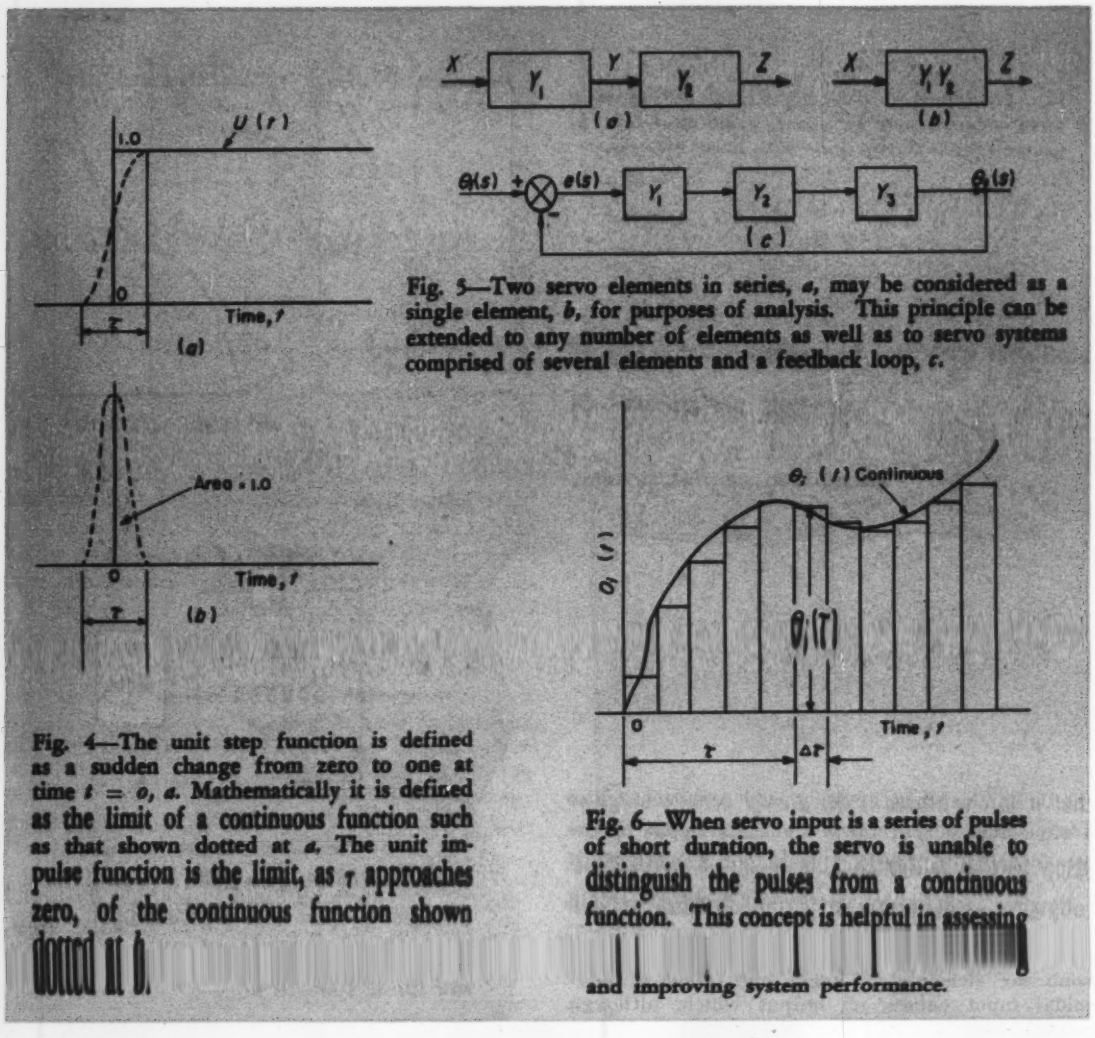


Fig. 5—Two servo elements in series, *a*, may be considered as a single element, *b*, for purposes of analysis. This principle can be extended to any number of elements as well as to servo systems comprised of several elements and a feedback loop, *c*.

Fig. 4—The unit step function is defined as a sudden change from zero to one at time $t = 0$, *a*. Mathematically it is defined as the limit of a continuous function such as that shown dotted at *a*. The unit impulse function is the limit, as τ approaches zero, of the continuous function shown dotted at *b*.

Fig. 6—When servo input is a series of pulses of short duration, the servo is unable to distinguish the pulses from a continuous function. This concept is helpful in assessing and improving system performance.

ous function, such as that shown dotted in Fig. 4*a*, as the build-up time τ tends to zero. When defined in this way the function is called the *Heaviside unit step function* $U(t)$.

2. *Unit Impulse Function:* This is defined as the limit as $\tau \rightarrow 0$ of the continuous function shown dotted in Fig. 4*b*. The function is continuous, equally spaced about the origin and its area remains unity as $\tau \rightarrow 0$. Defined in this way, the function is called the *Dirac unit impulse* $\delta(t)$; it is the derivative of $U(t)$. Terms $U(t - t_0)$ and $\delta(t - t_0)$ are respectively unit step and unit impulse functions at time t_0.

The Laplace transform $\overline{f}(s)$ of a function $f(t)$ is defined as

$$\overline{f}(s) = \lim_{h \rightarrow 0} \int_{-h}^{\infty} f(t)\, e^{-st}\, dt \qquad (4)$$

or as it is normally written

$$\overline{f}(s) = \int_{0-}^{\infty} f(t)\, e^{-st}\, dt \qquad (4a)$$

Making the lower limit of integration 0-, instead of simply 0, insures that the full contribution of any impulse function at the origin is included.

Many textbooks give comprehensive tables of Laplace transforms. The more important ones are listed in Table 1.

In servo work, only functions which are zero for negative time are involved. The time origin, $t = 0$ is the time when an input is applied to the system. Some extremely useful theorems for such functions are given in Table 2. In connection with these theorems the following notation is used:

$$\overline{f}(s) = \mathcal{L} f(t), \quad f(t) = \mathcal{L}^{-1} \overline{f}(s)$$

To illustrate the application of the theorems in Table 2 to the solution of differential equations, Theorems 1 and 2 are first applied to Equation 1 to give

$$(ms^2 + fs + k)\, \overline{y}(s) = (fs + k)\, \overline{x}(s)$$

and since this equation can now be handled algebraically,

Table 1—Laplace Transforms For Servo Analysis

$f(t)$	$\overline{f}(s)$
$U(t)$	$1/s$
$\delta(t)$	1
t^n	$n!/s^{n+1}$
e^{at}	$1/(s - a)$
$\sin \omega t$	$\omega/(s^2 + \omega^2)$
$\cos \omega t$	$s/(s^2 + \omega^2)$

$$\bar{y}(s) = \left[\frac{(Fs+k)\,\bar{x}(s)}{ms^2+Fs+k} \right] \qquad (5)$$

Then if $x(t)$ is specified, $\bar{x}(s)$ can be obtained and substituted in Equation 5. The output can then be obtained as a function of time, t, by inverse transforming the right hand side of Equation 5. To do this a comprehensive table of transforms is very useful. However, the short list given in Table 1 may be expanded by using the theorems in Table 2. As a simple example

$$\mathcal{L}(e^{-at} \sin \omega t) = \frac{\omega}{(s+a)^2+\omega^2}$$

For any general element, by transforming Equation 2,

$$\frac{y}{x}(s) = \left(\frac{b_m s^m + \ldots + b_1 s + b_0}{a_n s^n + \ldots + a_1 s + a_0} \right) \equiv Y(s) \qquad (6)$$

where $Y(s)$ is a property of the element only and is called its *transfer function*. Obviously the transfer function of an element governed by a linear differential equation is a rational function of s, as shown in Equation 6.

As long as it is realized that transformed quantities are being considered the $\bar{x}(s)$ notation can be discarded and $x(s)$ or simply x can be used.

It is possible to represent each element by a simple block diagram. If two such elements are in series, the output of the first being the input to the second, Fig. 5*a*, and if they are governed by the respective equations,

$$\left.\begin{aligned} y &= Y_1 x \\ z &= Y_2 y \end{aligned}\right\} \qquad (7)$$

Then, since the equations can be handled algebraically

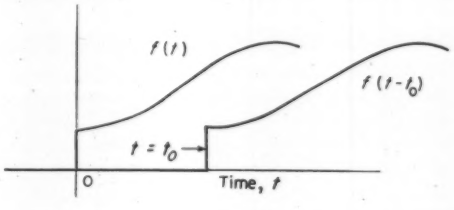
$$z = Y_1 Y_2 x \qquad (8)$$

This shows that the two boxes in series can be replaced by a single box containing the operator $Y_1 Y_2$ Fig. 5*b*. This can be extended to any number of elements in series. However, this is true only when the elements do not interact, that is, provided the output of any element depends only on its input and not upon the output of the succeeding elements. This is only approximately true in practice. Serious interaction results where the succeeding elements seriously overload the power source of the system. This will be discussed further in future articles.

This technique can be extended to a servo system comprising a sequence of noninteracting elements and a feedback loop, Fig. 5*c*. As shown here the system is a single-loop system. More

Table 2—Useful Theorems for Laplace Transforms

Theorem	No.
$\mathcal{L}[af(t) + bg(t)] = a\bar{f}(s) + \bar{b}g(s)$	1
where a, b are constants.	
$\mathcal{L}\left[\frac{df}{dt}\right] = s\bar{f}(s)$	2
$\mathcal{L}\left[\int_{0-}^{t} f(t)\,dt\right] = \frac{1}{s}\bar{f}(s)$	3
$\mathcal{L}[e^{-at} f(t)] = \bar{f}(s+a)$	4
$\mathcal{L}[F(t-t_0), U(t-t_0)] = e^{-st_0}\bar{F}(s)$	5
where $f(t-t_0)$ is $f(t)$ shifted forward by t_0.	



If

$$C(t) \equiv \int_{0-}^{\infty} f(\tau)\,g(t-\tau)\,d \equiv \int_{0-}^{\infty} g(\tau)\,f(t-\tau)\,d \qquad 6$$

then

$$\bar{C}(s) = \bar{f}(s)\,\bar{g}(s)$$

$$\mathcal{L}\left[tf(t)\right] = -\left[\frac{d}{ds}\bar{f}(s)\right] \qquad 7$$

$$\lim_{t\to\infty} f(t) = \lim_{s\to 0} [s\bar{f}(s)] \qquad 8$$

provided this limit exists.

$$\lim_{t\to 0+} f(t) = \lim_{s\to\infty} [s\bar{f}(s)] \qquad 9$$

provided this limit exists.

If $f(t)$ contains a term $A\,\delta(t)$,

then

$$A = \lim_{s\to 0} \bar{f}(s) \text{ and}$$

$$\lim_{t\to 0+} f(t) = \lim_{s\to\infty} [s\{f(s) - A\}]$$

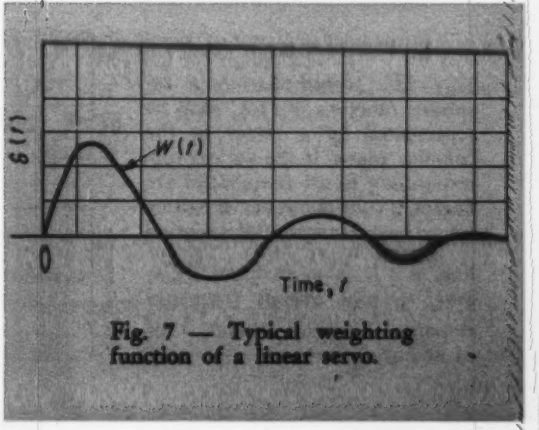


Fig. 7 — Typical weighting function of a linear servo.

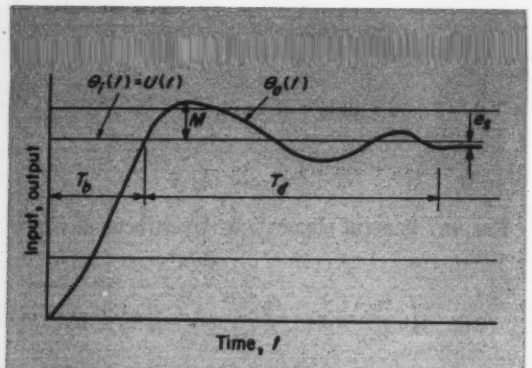


Fig. 8—Typical output response to a step function input shows pictorially the change in output corresponding to any sudden change in output corresponding to any sudden change in input.

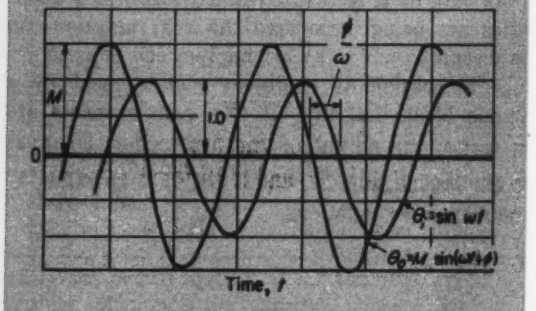


Fig. 9—Servo response to pure harmonic input is sinusoidal and of the same frequency. The amplitude, however, is increased in the ratio M:1 and phase is shifted by an angle, ϕ.

complicated multiloop systems differ only in detail rather than principle.

The transfer function relating the output, θ_o, to the error, e, of this circuit, Fig. 5*c*, is called the *open-loop* or the *loop* transfer function. This is

$$Y_o(s) \equiv \frac{\theta_o}{e}(s) = Y_1 Y_2 Y_3 \qquad (9)$$

At the differential we have the subtraction

$$e = \theta_i - \theta_o \qquad (10)$$

where θ_i is the input. Then by eliminating e from Equations 9 and 10

$$Y_c(s) \equiv \frac{\theta_o}{\theta_i}(s) = \left(\frac{Y_o}{1 + Y_o}\right) \qquad (11)$$

where $Y_c(s)$ which relates the transformed output and input of the servo is called the *closed-loop* or *overall transfer function.*

Although primary concern is with output-input relations, it is very convenient to work with the loop transfer function, Y_0 as will be shown. Individual transfer functions of servo elements are of the form

$$K, \frac{K}{s}, \frac{K}{1 + Ts}, \frac{K}{s(1 + Ts)}, \frac{K(1 + Ts)}{1 + T_1 s}, \frac{K}{1 + T_1 s + T_2^2 s^2},$$

and so on. If several of these are compounded in

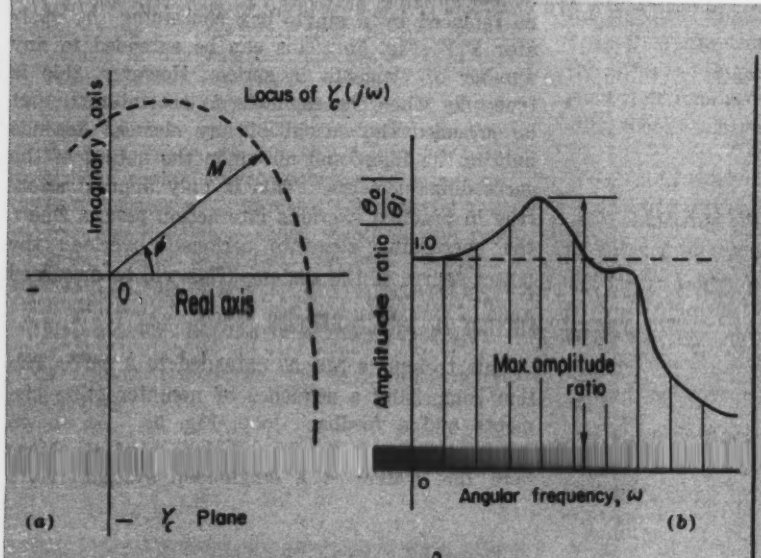
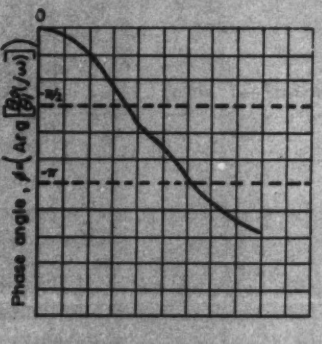


Fig. 10—Overall harmonic response function $Y_o(j\omega)$, may be represented by a vector in the complex plane. If the vectors corresponding to all frequencies are drawn, a continuous curve will be traced as shown by the dotted line, *a*. It is more usual, however, to plot overall frequency response as separate curves, *b*, of M and ϕ against ω.



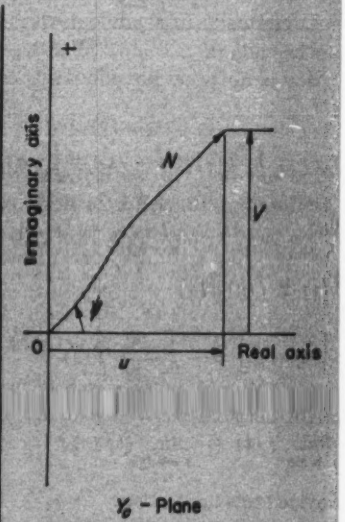


Fig. 11 — The loop harmonic function $Y_o(j\omega)$ is usually plotted as a vector in the complex plane. The real part, $u(\omega)$, is plotted on the horizontal axis while the imaginary part $v(\omega)$ is plotted vertically.

the loop of a servo, as in Fig. 5c, the loop transfer function will be of the form

$$Y_o(s) = \frac{K f(s)}{s^r g(s)} \tag{12}$$

where f and g are finite polynomials in s which tend to 1 as $s \to 0$. Thus f and g are of the form

$$\left.\begin{aligned} f(s) &= 1 + T_1 s + T_2^2 s^2 + T_3^3 s^3 + \dots \\ g(s) &= 1 + (T_1')s + (T_2')^2 s^2 + \dots \end{aligned}\right\} \tag{13}$$

where K is a constant called the *scalar gain constant* of the system. It is sometimes called simply the gain, but this may lead to confusion with a similarly named term.

From Equation 11 it follows that

$$Y_c(s) = \frac{Kf(s)}{Kf(s) + s^r g(s)} \tag{14}$$

This can be written in the more general form

$$Y_c(s) = \frac{F(s)}{G(s)} = \left(\frac{b_m s^m + \dots + b_1 s + b_0}{a_n s^n + \dots + a_1 s + a_0} \right) \tag{15}$$

Comparing this with Equation 6 shows that the servo is itself a linear filter, operating on the input to give the output. If $\theta_i(t)$ and hence $\theta_i(s)$ are known, then the output $\theta_o(t)$ can be found from

$$\theta_o(t) = \mathcal{L}^{-1}[Y_c(s)\,\theta_i(s)] \tag{16}$$

Servo Input Functions: It is not possible to generalize on the type of input likely to be encountered in servo work. Indeed the kinds of inputs normally encountered do not yield themselves to analytical expression. Instead, three idealized input functions upon which to base an analytical approach are chosen. They are:

1. *Unit Impulse Function,* $\delta(t)$: Here $\theta_i(s) = 1$. The output in this case is called the *Weighting Function,* $W(t)$, of the system. From Equation 16

$$W(t) = \mathcal{L}^{-1}[Y_c(s)] \tag{17}$$

or

$$Y_c(s) = \mathcal{L}\,W(t) \tag{18}$$

This shows that the weighting function is an important property of the servo. From Equations 16 and 18 and Theorem 6, it can be seen that if $W(t)$ is known, the response to any input $\theta_i(t)$ can be found from

$$\theta_o(t) = \int_{0-}^{\infty} \theta_i(\tau)\, W(t-\tau)\, d\tau \tag{19}$$

Thus the response to a complicated input can be obtained.

If the input can be thought of as a series of impulses of duration, $\Delta\tau$, Equation 19 means that as $\Delta\tau$ becomes very small the system is unable to distinguish between the series of impulses and continuous input, Fig. 6. This concept is very helpful in assessing and improving the performance of existing systems, for if $W(t)$ can be determined experimentally, it is possible to calculate how the system will respond to any input. The difficulty is to generate an impulse of sufficiently short duration to approximate a δ-function. Generally, if the duration of the pulse is much smaller than any natural period of the system, very good results are obtained.

If the denominator of $Y_c(s)$ is expressed in the form

$$G(s) \equiv (s - h_1)(s - h_2) \dots (s - h_n) \tag{20}$$

where $h_1, h_2, \dots, h_n$ are the roots of $G(s) = 0$, called the *characteristic equation,* $Y_c(s)$ can be split into partial fractions, thus

$$Y_c(s) = \frac{A_1}{s - h_1} + \frac{A_2}{s - h_2} + \dots + \frac{A_n}{s - h_n} \tag{21}$$

where $A_1, A_2, \dots$ are the normal partial fraction constants.

Then using Table 1

$$W(t) = A_1 e^{h_1 t} + A_2 e^{h_2 t} + \dots + A_n e^{h_n t} \tag{22}$$

It has been assumed that the roots of the char-

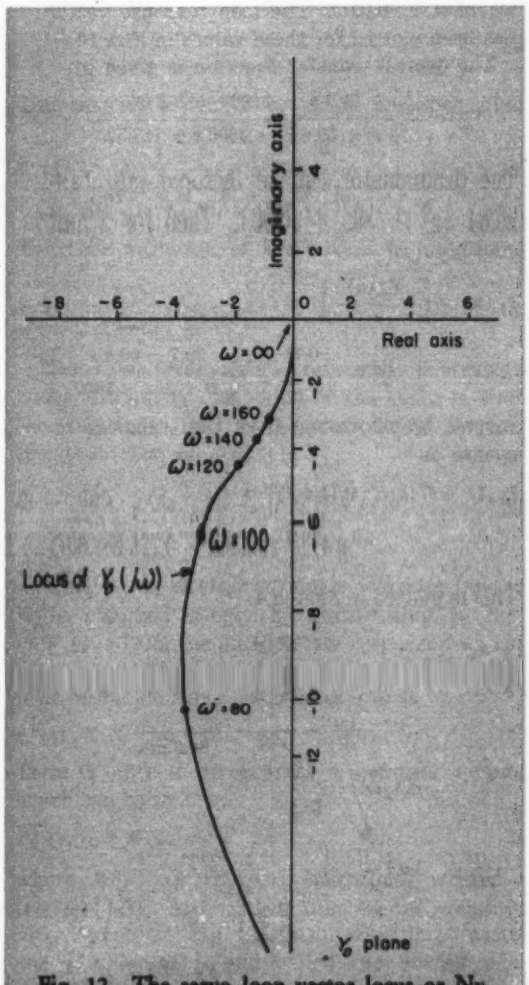


Fig. 12—The servo loop vector locus or Nyquist plot is of great value in servo analysis. It is obtained by plotting the loop harmonic response function, $Y_o(j\omega)$, for values of ω from zero to infinity.

acteristic equation are all distinct. If, on the other hand, there are repeated roots such as $(s\text{-}h)^2$, the weighting function will contain terms such as Bte^{ht}. The most general form of the weighting function is, therefore, written

$$W(t) = \sum (A + Bt + Ct^2 + Dt^3 + \dots)\, e^{ht} \qquad (23)$$

A typical weighting function of a linear servo is shown in Fig. 7.

2. Unit Step Function $U(t)$: Here $\theta_i(s) = 1/s$ and from Equation 11

$$\theta_o(s) = \frac{Y_c(s)}{s} \qquad (24)$$

From Theorem 3, Table 2, it follows that

$$\theta_o(t) = \int_{0-}^{t} W(t)\, dt \qquad (25)$$

It is more likely that the response to a step function would be obtained directly from Equation 24. Thus expanding by partial fractions

$$\theta_o(s) = \frac{A_0}{s} + \frac{A'_1}{s - h_1} + \dots + \frac{A'_n}{s - h_n} \qquad (26)$$

where, in general,

$$A_0 = Y_c(0),\ A'_r = s \xrightarrow{\lim} h_r \left[\frac{(s - h_r)\, F(s)}{sG(s)} \right]$$

The general form of the output response, if there are repeated roots in the characteristic equation

Manipulation of Complex Quantities

Addition: Two response functions such as $N_1 e^{j\psi_1}$ and $N_2 e^{j\psi_2}$ must be added according to the parallelogram law of vectors, Sketch 1.

Multiplication: If $Ne^{j\psi} = N_1 e^{j\psi_1} \times N_2 e^{j\psi_2}$, then $N = N_1 N_2$; that is, moduli are multiplied, and $\psi = \psi_1 + \psi_2$, the phase angles are added, Sketch 2.

Division: If $Ne^{j\psi} = N_1 e^{j\psi_1}/N_2 e^{j\psi_2}$, then $N = N_1/N_2$ and $\psi = \psi_1 - \psi_2$.

To illustrate the application of these methods, suppose $Y_o(j\omega)$ is known for a particular frequency. Then $1 + Y_o(j\omega)$ can be obtained by addition, Sketch 3*a*, and $Y_c(j\omega)$ can then be obtained by division from Equation 36, as shown in Sketch 3*b*.

Numerical Example: Suppose a servo has the loop transfer function

$$Y_o(s) = \frac{51.3\,(1 + 0.0225\,s)\,(1 + 0.2\,s)}{s\,(1 + 0.00435\,s + 0.00045\,s^2)}$$

Then the loop response function is

$$Y_o(j\omega) = \frac{51.3\,(1 + 0.0225\,j\omega)\,(1 + 0.2\,j\omega)}{j\omega\,(1 - 0.00045\,\omega^2 + 0.00435\,j\omega)}$$

Thus the modulus and phase are given. To change to a more convenient frequency scale,

$$N \equiv |Y_o(\Omega)| = \frac{0.513}{\Omega} \sqrt{\frac{(1 + 5.06\Omega^2)\,(1 + 400\Omega^2)}{(1 - 4.5\Omega^2)^2 + 0.19\Omega^2}}$$

$$\psi \equiv \arg\ Y_o(\Omega) = \tan^{-1}(2.25\,\Omega) + \tan^{-1}(20\,\Omega) - \tan^{-1}\left(\frac{0.435\,\Omega}{1 - 4.5\,\Omega^2}\right) - \frac{\pi}{2}$$

where $\Omega = 0.01w$. The loop response vector has been plotted for these values in Fig. 16.

The overall transfer function is given by

$$Y_c(s) = \frac{50.4\,s^2 + 2490\,s + 113{,}000}{s^3 + 59.6\,s^2 + 4690\,s + 113{,}300}$$

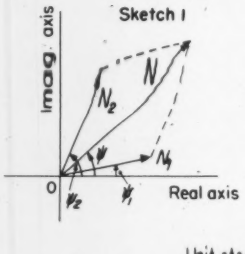
The denominator can be factored into $(s + 29.6)\,(s^2 + 30s + 3800)$. Then for a unit step input

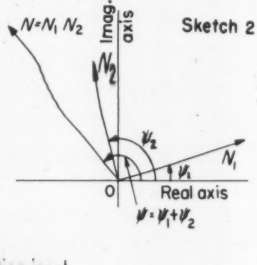
$$\theta_o(s) = \left[\frac{Y_c(s)}{s}\right] = \left[\frac{1}{s} - \frac{0.71}{s + 29.6} + \frac{20.7 - 0.29\,s}{s^2 + 30s + 3800}\right]$$

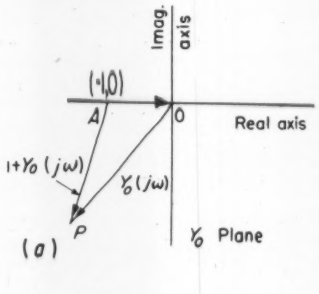
Inverse transforming gives the transient response as

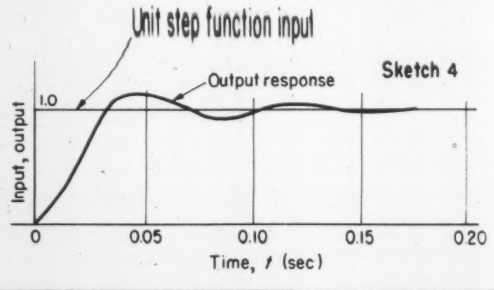
$$\theta_o(t) = U(t) - 0.71\,e^{-29.6t} + 0.4\,e^{-15t}\,(\sin 60t - 0.725\cos 60t)$$

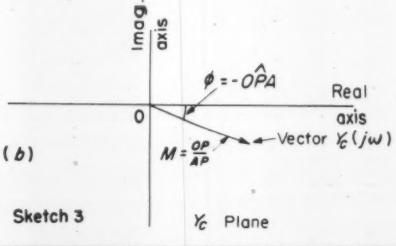
This is plotted in Sketch 4.











is, therefore,

$$\theta_o(t) = A_o U(t) + \sum [(A' + B' + C' t^2 + \ldots +) e^{ht}] \quad (27)$$

A typical response is shown in Fig. 8. Such a curve is very informative because it gives a simple pictorial representation of the response to a sudden jump in the input. Thus, in the diagram, T_r gives a measure of the sensitivity, e_s gives a measure of the steady-state accuracy, and M and T_d give measures of the stability.

3. Sinusoidal Input Function: Output here is called the *frequency response.* Instead of a real sinusoidal input, eg. sin ωt, the complex form of a harmonic quantity will be considered, that is

$$\theta_i = e^{j\omega t} \equiv (\cos \omega t + j \sin \omega t) \quad (28)$$

where ω is the frequency in radians per second, and j is the symbolic quantity for $\sqrt{-1}$. This is a dodge which greatly simplifies the mathematics. It is justified because of the principle of linear superposition, since the real part of the output can be considered as the response of cos ωt and the imaginary part as the response to sin ωt.

From Table 1 $\theta_i(s) = 1/(s - j\omega)$ and, therefore,

$$\theta_o(s) = \left[\frac{Y_c(s)}{s - j\omega}\right] = \frac{F(s)}{(s - j\omega)\, G(s)} \quad (29)$$

This may be expanded in partial fractions, giving

$$\theta_o(s) = \sum \left[\frac{A}{s - h}\right] + \frac{B}{s - j\omega} \quad (30)$$

The time variation of the output is, therefore,

$$\theta_o(t) = \sum A e^{ht} + B e^{j\omega t} \quad (31)$$

The first term, $\Sigma A e^{ht}$, represents a transient which ultimately disappears if the servo is stable. The remainder $Be^{j\omega t}$ is the *steady-state frequency response.* The value of B is

$$B = \lim_{s \to j\omega} [(s - j\omega)\, \theta_o(s)] = Y_c(j\omega) \quad (32)$$

$Y_c(j\omega)$ is the *overall harmonic response function.* It is obtained simply by substituting $j\omega$ for s in $Y_c(s)$. Thus the steady-state response to a complex harmonic input of frequency ω is

$$\theta_o(t) = Y_c(j\omega)\, e^{j\omega t} \quad (33)$$

Term $Y_c(j\omega)$ is in general a complex quantity which can be written

$$Y_c(j\omega) = M(\omega)\, e^{j\phi(\omega)} \quad (34)$$

where $M(\omega) = |Y_c(j\omega)|$, sometimes written as $|(\theta_o/\theta_i)(j\omega)|$, and called the *overall amplitude ratio;* $\phi(\omega) = \arg [Y_c(j\omega)]$, sometimes written arg $[(\theta_o/\theta_i)(j\omega)]$, and called the *overall phase angle.* Thus Equation 33 can be written

$$\theta_o(t) = M e^{j(\omega t + \phi)} = M [\cos(\omega t + \phi) + j \sin(\omega t + \phi)] \quad (35)$$

Separating the real and imaginary parts shows that the response to the real inputs cos ωt and sin ωt are respectively $M\cos(\omega t + \phi)$ and $M \sin(\omega t + \phi)$. That is, the response to any pure harmonic input is also sinusoidal and of the same frequency, but the amplitude is increased in the ratio $M : 1$, and the phase is shifted by an angle ϕ with respect to the input, Fig. 9. In practical systems the output will lag the input; that is, ϕ will be negative.

It is possible to draw $Y_c(j\omega)$ as a vector in the complex plane. If this vector is drawn for all frequencies between 0 and ∞, then its end point will trace out a continuous curve in the Y_c-plane, as shown dotted in Fig. 10*a*. In practice, however, it is more usual to plot the overall frequency response characteristics as separate curves of M and ϕ plotted against ω, Fig. 10*b*.

Just as it is possible to work with the loop transfer function, the loop harmonic response function, $Y_o(j\omega)$, can also be used. This is obtained simply by putting $s = j\omega$ in $Y_o(s)$. Then

$$Y_c(j\omega) = \frac{Y_o(j\omega)}{1 + Y_o(j\omega)} \quad (36)$$

It is usual to plot $Y_o(j\omega)$ as a vector in the complex-plane. To do this $Y_o(j\omega)$ must be expressed in the form; $Y_o(j\omega) = u(\omega) + jv(\omega)$ where $u(\omega)$ is the real part and is plotted along the horizontal axis and $v(\omega)$ is the imaginary part and is plotted vertically, Fig. 11.

Alternatively, the loop harmonic response function may be expressed as

$$Y_o(j\omega) \equiv \left[\frac{\theta_o}{e}(j\omega)\right] = N(\omega)\, e^{j\psi(\omega)} \quad (37)$$

where $N(\omega) = |Y_o(j\omega)| = \sqrt{u^2 + v^2}$, and is called the *loop gain* or *loop amplitude ratio* and $\psi(\omega) = \arg [Y_o(j\omega)] = \tan^{-1}(v/u)$, and is the loop phase angle.

As ω is varied from 0 to ∞, the tip of the $Y_o(j\omega)$ vector will trace out a continuous curve in the Y_o-plane, Fig. 12. This curve is called the *loop vector locus* or the *Nyquist plot.* Its very great value in servo analysis will be discussed in the next article, which will deal with performance criteria.

Bibliography

This article is the second in a co-ordinated group by J. M. Nightingale on servo systems. The previous article and the issue of MACHINE DESIGN in which it appeared is:

1. "Automatic Control Systems" .....May 17, 1956

Other helpful sources of information on points discussed in this article are:

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Dimension Control in Design

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THE DISTINCTION between variation in a train of mechanisms, and variation in a simple dimension system is given in Part 4 of this series. Variations, it may be remembered, are not only associated with action of a mechanism, but with mechanical construction; that is, with problems of fastening, enclosing, sealing, and so forth.

In Part 4 simple dimension systems are grouped into two categories: (1) *direct* variation relationships, and (2) *indirect* variation relationships. These categories are just as useful in this article. Because of the differences in the underlying assumptions, however, the calculation of dimension relationships lead to very different results.

One of the consequences of the use of probability methods, in comparison to the use of the non-probability methods of Part 4, is that the formulas involved are generally more difficult to handle mathematically. However, for certain special dimension relationships, simplified calculations give good enough results, and greatly lessen the labor.

Direct Variation Relationships: The slip ring assembly shown in *Fig.* 29 (originally shown in Part 5) illustrates a direct variation relationship. If precision and accuracy of the dimensions were defined by limits only, then the variation v of the dimension condition y would be the sum of the tolerances, $t_a + t_b + \ldots + t_f$. However, if the dimensions have probability distributions, variation is something else.

The development of an equation for the variation v of a probability-distributed dimension condition follows the same pattern as the development of the equation of train variation. First an equation of random variables is formed. To this equation is associated a relationship of standard deviations, according to the rules already given. Finally, a new equation is obtained from the relationship of standard deviations by making use of the connection between variation and standard deviation, and tolerance and standard deviation.

Variation of a probability distributed dimension condition has already been symbolized by v. A convenient notation for a probability distributed tolerance is τ.

From *Fig.* 29, the variation of the dimension condition, the gap for the bowed retaining ring, is

$$v = \tau_a + \tau_b + \ldots + \tau_f$$

so that

$$\sigma^2 = \sigma_a^2 + \sigma_b^2 + \ldots + \sigma_f^2$$

if all the dimensions are independent.

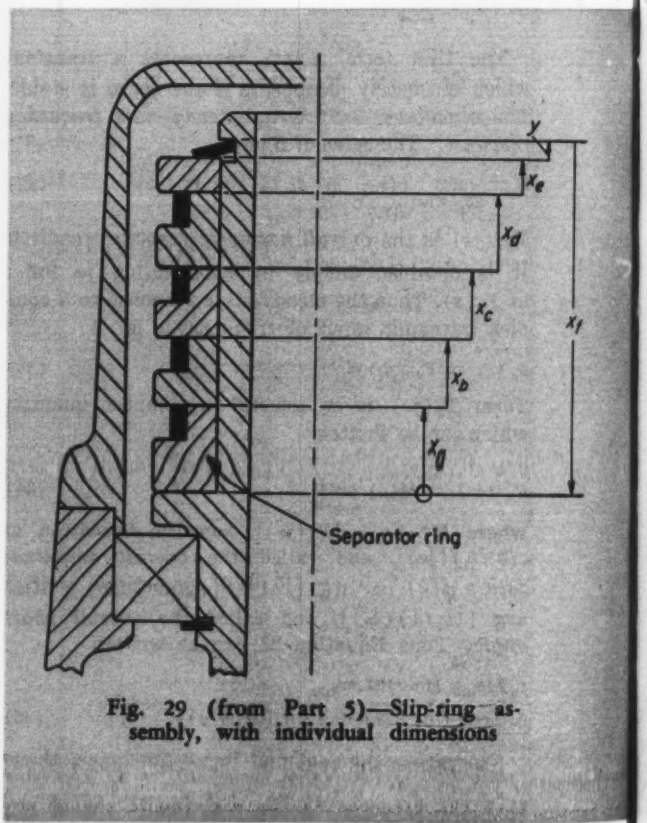


Fig. 29 (from Part 5)—Slip-ring assembly, with individual dimensions

A systematic study of methods for controlling effects of tolerances and design geometry

Part 6—Probability Dimensioning Methods for Determining Tolerances

Consider first the case of the dimensions having normal distributions. Considering the previous equation, and multiplying by a factor U^2, a new equation can be written

$$(U\sigma_p)^2 = (U\sigma_{pa})^2 + (U\sigma_{pb})^2 + \ldots + (U\sigma_{pf})^2$$

The term $U\sigma_p$ is equivalent to the variation v of the dimension condition; the other terms, $U\sigma_{pa}$, $U\sigma_{pb}$, etc., are equivalent to the tolerances t_a, t_b, etc. The distinction between the random variable τ and variation v is shown in Fig. 34. A similar comparison could of course be drawn between τ and t.

It is convenient to adopt a base value of U from which higher or lower levels of risk may be taken. Thus, if the above equation is multiplied by $(U_P/U)^2$, where U_P corresponds to the new level of risk, then

$$(U_P\sigma_p)^2 = \left(\frac{U_P}{U}\right)^2 [(U\sigma_{pa})^2 + (U\sigma_{pb})^2 + \ldots + (U\sigma_{pf})^2]$$

which is equivalent to

$$v_P^2 = R^2 (t_a^2 + t_b^2 + \ldots + t_f^2) \qquad (22)$$

where

$$R = \frac{U_P}{U} \qquad (23)$$

The significance of R is illustrated in *Fig.* 35. Decreasing the value of R is equivalent to increasing the value of the tolerances, yet maintaining the same value of variation by accepting a greater level of risk.

Two kinds of risk are implicit in the factor R: one associated with U_P, and the other with U. The risk associated with U_P is a *design* risk. Thus, if all dimensions fall within tolerance, then the probability that the dimension condition will fall within tolerance is denoted by P. On the other hand, the risk associated with U is a *manufacturing* risk.

From Equation 22, when the distributions of the tolerances are normal, the distribution of the variation is also normal. Thus, U must be a function of u, where u is the standardized normal variable. This fact is important in setting the level of risk because every value of u has a corresponding theoretical probability (see *Fig.* 5 in Part 1).

In Part 1, tolerance for a normally distributed dimension is defined by

$$t = \left(\frac{\sqrt{\rho^2 + 1}}{\rho} 2u\right)\sigma_p$$

where ρ stands for the ratio of the standard deviation of the manufacturing process σ_p, to the standard deviation σ_m of other sources of inaccuracy—inaccuracies due to measurement errors, temperature effects, and so forth. In the development of Equation 22 it was assumed that

$$t = U\sigma_p$$

By equating similar terms in this and the preceding equation,

$$U = \left(\frac{\sqrt{\rho^2 + 1}}{\rho}\right) \qquad (24)$$

In Table 1 (Part 1), values of U are given for several combinations of values of ρ and u. Thus, in a manufacturing process, if the standard deviation of the process is no greater than σ_p, and if the actual value of ρ is not less than that assumed, then the manufacturing risk correspond-

Table 7—Values of Risk for Rectangularly Distributed Dimensions

P =	0.99999	0.99990	0.99950	0.99900	0.99000	0.90000
R =	2.55	2.24	2.01	1.90	1.49	0.95

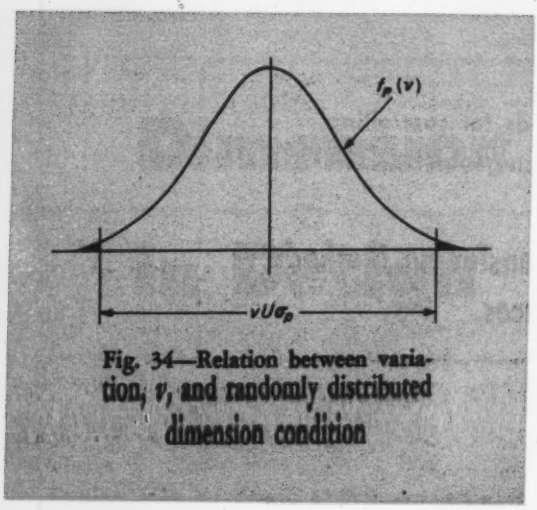


Fig. 34—Relation between variation, v, and randomly distributed dimension condition

ing to the choice of a value for u in the above equation will not be exceeded.

For example, when $U = 8$, and if $\rho \geqq 3$, then from *Table* 1, $u \geqq 3.79$ which corresponds to a manufacturing risk $P \geqq 0.9998$ if the value of σ_p is known or, at any rate, if the assumed value is not larger than the actual value.

Even though Equation 22 was developed for normally distributed dimensions, it is still valid for dimensions that have rectangular distributions if

$$R = \frac{U_P}{\sqrt{12}} \qquad (25)$$

instead of U_P/U as in Equation 23. This statement can be proved by redeveloping Equation 22 in about the same way as before. Instead of using the relationship, $t = U\sigma_p$ which is correct only when the dimensions are normally distributed the corresponding relationship between tolerance and standard deviation for a rectangular distribution is used; that is, $t = \sqrt{12}\,\sigma_p$.

In Tables 7 and 8, values of R for rectangularly and normally distributed dimensions are given for several levels of design risk. Values of R in *Table* 8 correspond to values of U found in Table 1 (Part 1).

The question may be asked: What if some of the dimensions in a relationship are not independent? To illustrate the point, suppose x_a, x_b, x_c and x_d in the slip ring assembly are not independent because the separator rings are all molded in the same die. It may be assumed that the value of one dimension will be the same for all. Therefore,

$$v = 4\,\tau_a + \tau_e + \tau_f$$

By starting with the relationship of standard deviations that corresponds to the above equation, and proceeding as before, the result is

$$v_P^2 = R^2\,(16\,t_a^2 + t_e^2 + t_f^2) \qquad (26)$$

where $t_a = t_b = t_c = t_d$.

Thus, by using Equations 22 and 26, tolerances may be calculated for the slip ring assembly when the dimensions are either:

1. Normally distributed and all independent.
2. Rectangularly distributed and all independent.
3. Normally distributed and x_a, x_b, x_c and x_d dependent.
4. Rectangularly distributed and x_a, x_b, x_c and x_d dependent.

A comparison of results based on these alternatives is shown in *Table* 9. Tolerances are shown for two levels of risk. Also included in the table are tolerances assigned by nonprobability method of Part 4; that is, when the variation of the dimension condition is merely the sum of the tolerances.

Note in *Table* 9 that for dimensions assumed to have rectangular distributions, some of the tolerances are smaller than the tolerances assigned to

Nomenclature

$A, a; B, b; \ldots$ = Upper (maximum) and lower (minimum) tolerance limits, respectively, for the dimensions x_a, x_b, . . .
e = Eccentricity
n = Number of units being considered
P = Probability that a dimension or dimension condition will occur within its limits
R = Factor of risk = U_P/U
t = Tolerance, equal to the maximum tolerance limit minus the minimum tolerance limit in limit dimensioning
U = Factor of manufacturing risk
U_P = Factor of design risk
v = Variation of a dimension condition
W, w = Upper (maximum) and lower (minimum) limits for a dimension condition, y_w
x = Dimension (a variable)
y = Dimension condition, a dimension which results from combining two or more other dimensions
ε = Probability-distributed eccentricity
ν = Probability-distributed dimension condition
ρ = Ratio, standard deviations of processing to measuring distributions, σ_p/σ_m
σ = Standard deviation of a probability distribution
τ = Probability-distributed tolerance

Subscripts

$a, b, \ldots$ = Individual linear dimensions
j = Generalized number representing any individual unit
m = Of a measuring distribution
n = Number representing the last unit in a group
P = Associated with probability P
p = Of a processing distribution
w = Individual dimension condition
ω = Individual angular dimension condition
$1, 2, 3, \ldots$ = Numbers representing individual units in a group

satisfy the nonprobability relationship. For the type of relationship illustrated by the slip ring assembly, probability methods are not applicable if the dimensions are rectangularly distributed, unless the number of independent dimensions is equal to or greater than the amount shown in *Table* 10 for the level of design risk assumed. In no case should less dimensions be accepted and, depending on the particular relationship in question, even more may be necessary. When there is a reason for doubting the advantage of using probability methods over nonprobability methods, tolerances may be calculated for both cases and the most favorable set used; that is, the set of largest tolerance values.

To solve either Equation 22 or 26 an assumption must be made concerning the relationship of the tolerances to each other. The object of an assumption should be toward approximating a distribution of tolerances that satisfies the required value of variation as economically as practical. The values for probability-distributed tolerances in *Table* 9, for instance, are based on the assumed relationship,

$$t_a^2 = t_b^2 = t_c^2 = t_d^2 = \frac{3}{2} t_e^2 = \frac{3}{5} t_f^2$$

The coefficients of these t^2 terms correspond to the relative magnitudes of the tolerances assigned to satisfy the nonprobability relationship; the assumption for the nonprobability tolerances is

$$t_a = t_b = t_c = t_d = \frac{3}{2} t_e = \frac{3}{5} t_f$$

Methods for working out dimensions that satisfy the probable limits of the dimension condition, w_P and W_P, are not quite as straightforward as when nonprobability considerations are involved. For example, in the slip ring assembly of *Fig.* 29, the probable limits of the dimension condition are chosen so that the bowed retaining ring will function properly at the level of risk P. Six dimensions control y_w; limits for five of these dimensions may be arbitrarily assigned, the limits agreeing with the tolerances of the dimensions.

The nominal, or design size, of each dimension is, of course, assigned or scaled from the design layout. To calculate either the high or low limit of the remaining undertermined dimension, it is convenient to work with one of the *apparent* limits, w' or W'.

These apparent limits are based on the extreme combination of dimensions. The relationship between the probable limits and the apparent limits

Table 8—Values of Risk for Normally Distributed Dimensions

U	P=0.99999	0.99990	0.99950	0.99900	0.99000	0.90000
4.12	R=2.14	R=1.89	R=1.69	R=1.60	R=1.25	R=0.80
4.20	2.10	1.85	1.66	1.57	1.23	0.78
4.48	1.97	1.74	1.55	1.47	1.15	0.73
6.18	1.43	1.26	1.12	1.06	0.84	0.53
6.30	1.40	1.23	1.10	1.04	0.82	0.52
6.72	1.31	1.15	1.03	0.98	0.77	0.49
7.79	1.15	1.00	0.90	0.85	0.66	0.42
8.00	1.10	0.97	0.87	0.82	0.65	0.41
8.24	1.07	0.94	0.85	0.80	0.63	0.40
8.40	1.05	0.93	0.83	0.78	0.62	0.39
8.46	1.04	0.92	0.82	0.77	0.61	0.39
8.96	0.99	0.87	0.80	0.74	0.58	0.37

Example: When U=8.00 and the level of design risk P=0.99950, then R=0.87

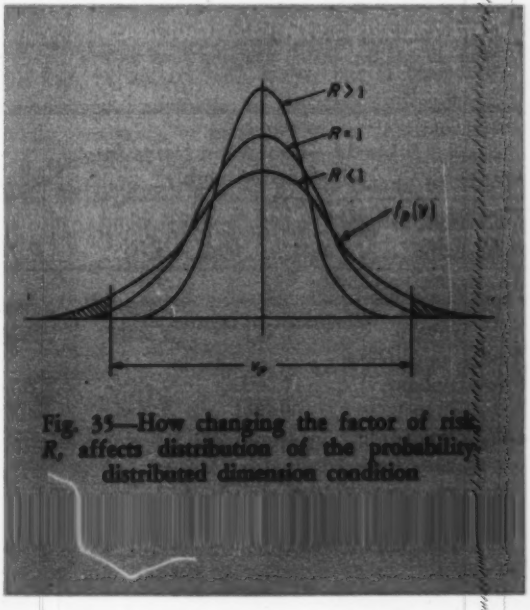


Fig. 35—How changing the factor of risk, R, affects distribution of the probability-distributed dimension condition

Table 9—Tolerance Comparison for Slip-Ring Assembly*

Tolerance	Probability P	Probability Methods $v_P = R\,(t_a^2 + t_b^2 + \ldots + t_f^2)^{1/2}$ All Dimensions Independent		x_a, x_b, x_c and x_d Not Independent		Limit Method $v = t_a + t_b + \ldots + t_f$
		Normal	Rect.	Normal	Rect.	
t_a, t_b, t_c, t_d	0.99999	0.0069	0.0030	0.0040	0.0017	0.0030
	0.99950	0.0087	0.0038	0.0051	0.0022	
t_e	0.99999	0.0056	0.0023	0.0033	0.0014	0.0020
	0.99950	0.0071	0.0031	0.0042	0.0018	
t_f	0.99999	0.0089	0.0039	0.0052	0.0022	0.0050
	0.99950	0.0112	0.0049	0.0066	0.0028	

**Fig.* 29; $v_P = v = 0.019$-in.; $U = 8$.

for the dimension condition y_w is shown in *Fig.* 36. From the relationship shown in *Fig.* 29, the lower limit of the dimension x_f,

$$f = A + B + C + D + E + w'$$

where

$$w' = w_P - \frac{v' - v_P}{2}$$

$$v' = t_a + t_b + \ldots + t_f$$

and v_P is defined by *Equation* 22.

Dimensions are given in *Table* 11 which satisfy the dimension condition, y_w = 0.035/0.054-inch. One set of dimensions is for the nonprobability assumption, and the other for the probability assumption. A purpose of the table is to afford a comparison of results of the two different methods and, moreover, to show how the way in which the precision and accuracy of dimensions are defined is ultimately reflected in the limits of the manufacturing dimensions.

Table 10—Least Number, *n*, of Independent Dimensions for Assumption of Rectangular Distribution*

P =	0.99999	0.99990	0.99950	0.99900	0.99000	0.90000
n =	8	6	5	4	3	—

*For simple dimension systems such as *Fig.* 29.

Table 11—Dimension Limits for Slip-Ring Assembly*

Dimension, described by limits	$A/a, \ldots, D/d$	E/e	F/f
Limits, nonprobability assumption	0.5000	0.2500	2.2900
	0.4970	0.2480	2.2850
Limits, probability assumption	0.5000	0.2500	2.2824
	0.4931	0.2444	2.2735

*For controlling retaining ring gap, *Fig.* 29. All dimensions in inches; $w = w_P$ = 0.035-in.; $W = W_P$ = 0.054-in.; P = 0.99999.

In the slip ring problem, the variation of the dimension condition is described quite nicely by a straightforward mathematical model. However, some problems may involve a large number of sources of variation in such a complicated relationship that a mathematical model cannot be more than a greatly simplified representation.

Thus, in applying probability techniques to the computation of tolerances for the coupling in the mechanism train (*Figs.* 23 and 25 in Part 2), it is hardly sensible to demand much in the way of mathematical exactness; the number of sources of variation and their complicated nature makes this impractical. The eccentricities, for instance, are vectors. The modulus of these vectors may, according to whatever assumption is followed, have either a rectangular or a normal distribution; the distribution of the angular position, or argument, is expected to be rectangular from 0 to 2π radians.

Because so many factors affect alignment of the shafts, it is not unreasonable to assume that the misalignment is approximately normally distributed. The basis for this argument is the central limit theorem; the argument is valid as long as there are no exaggerated sources of variation which have a pronounced effect on the final result.

The two primary sources of variation in the coupling, let it be assumed, are the play between the pin and the slot, and the eccentricity of the shaft. Thus, forgetting about the variation due to the minimum clearance between the pin and the slot, the equation of random variables

$$r_2 = \frac{\tau_a + \tau_B}{r} + \frac{\varepsilon}{r}$$

Table 12—Tolerance Comparison for Overrunning Clutch*

	t_a	t_b	t_c
Nonprobability	0.0018	0.0018	0.0019
Probability	0.0027	0.0027	0.0029

**Fig.* 28, Part 4. All dimensions in inches. Probability values assume R = 1.1.

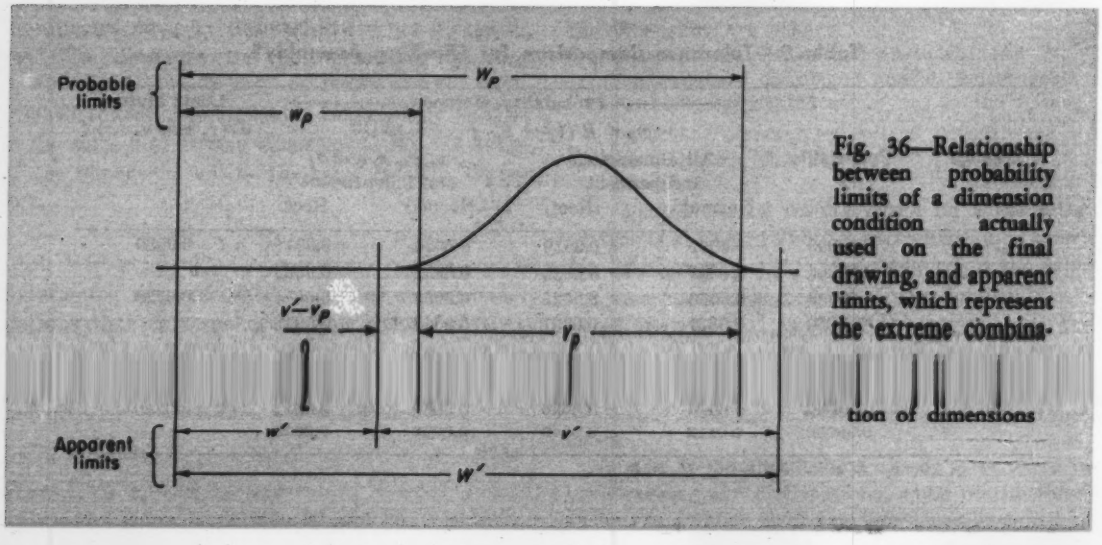


Fig. 36—Relationship between probability limits of a dimension condition actually used on the final drawing, and apparent limits, which represent the extreme combination of dimensions

is used to derive an equation for the v_{P2} term that was assigned a value of 0.0114-radian in *Table* 6 (Part 5). The preceding equation should be compared with Equations 9 and 11 in Part 4. By the same method used before, the above equation can be transformed into

$$v_{P2}^2 = \left(\frac{R}{r}\right)^2 (t_a^2 + t_B^2 + e^2)$$

where e is calculated as shown in Part 4.

Assume the same data as in Part 4; also assume that $R = 1.1$ and that $0.7\,t_a = t_B$. The solution of the above expression is then $t_a = 0.0061$ and $t_B = 0.0051$-inch. Compare these values with those calculated in Part 4: $t_a = t_B = 0.0004$-inch.

Indirect Dimension Relationships: An indirect variation relationship is defined in Part 4. The example of the overrunning clutch is recomputed here using probability methods. The equation of dimension condition of the clutch (*Fig.* 28 and *Table* 4, Part 4),

$$y_\omega = \cos^{-1}\frac{x_a - x_b/2}{x_c - x_b/2}$$

is a function of the form

$$y = f\,(x_1, x_2, \ldots, x_n)$$

which corresponds to Equation 13*a* (Part 5) if the y and x terms are random variables. Beginning with the relationship of standard deviations, the following general formula is developed:

$$v_P^2 = R^2\left[\left(\frac{\partial y}{\partial x_1}\right)^2 t_1^2 + \left(\frac{\partial y}{\partial x_2}\right)^2 t_2^2 + \ldots + \left(\frac{\partial y}{\partial x_n}\right)^2 t_n^2\right] \quad (27)$$

This equation may be solved for values of t that satisfy v_P by assuming some relationship between the t's. For instance, corresponding to the assumptions used before,

$$\left|\frac{\partial y}{\partial x_1}\right| t_1^2 = \left|\frac{\partial y}{\partial x_2}\right| t_2^2 = \ldots = \left|\frac{\partial y}{\partial x_j}\right| t_j^2 = \ldots = \left|\frac{\partial y}{\partial x_n}\right| t_n^2$$

from which

$$t_j = t_n\sqrt{\frac{|(\partial y/\partial x_n)|}{|(\partial y/\partial x_j)|}}$$

Substituting this expression in Equation 27 gives

$$v_P^2 = t_n^2 R^2 \left|\frac{\partial y}{\partial x_n}\right|\left(\left|\frac{\partial y}{\partial x_1}\right| + \left|\frac{\partial y}{\partial x_2}\right| + \ldots + \left|\frac{\partial y}{\partial x_{n-1}}\right| + 1\right)$$

from which t_n may be evaluated. The two preceding equations are applicable only if all the tolerances are unknown to start with. If this is not so, modified forms must be derived to suit.

However, the two equations have been used to calculate tolerance values for the overrunning clutch, assuming that the dimensions x_a, x_b and x_c are independent random variables, and $R = 1.1$. All other data are the same as in Part 4. Results are given in *Table* 12, compared with the results of Part 4.

Summary: By following the methods outlined in this part of the series, a designer should be able to apply probability principles to most dimension problems. Special and unusual problems will of course need more refined considerations.

The methods developed here stem from a very few fundamental ideas. Although the equation of variation for the slip ring was derived by first forming the direct variation relationship,

$$r = \tau_a + \tau_b + \ldots + \tau_f$$

it could also have been worked out by starting with the equation of dimension condition

$$y = x_f - (x_a + x_b \ldots + x_e)$$

The result is the same no matter what initial approach is taken:

$$v_P^2 = R^2\,(t_a^2 + t_b^2 + \ldots + t_f^2)$$

This illustration does not imply that all problems can be solved both ways, but it does show the common foundation of the two approaches.

Only two kinds of probability distributions have been considered here, although the usefulness of other distributions should by no means be ruled out. The following facts concerning normal and rectangular distributions should be remembered:

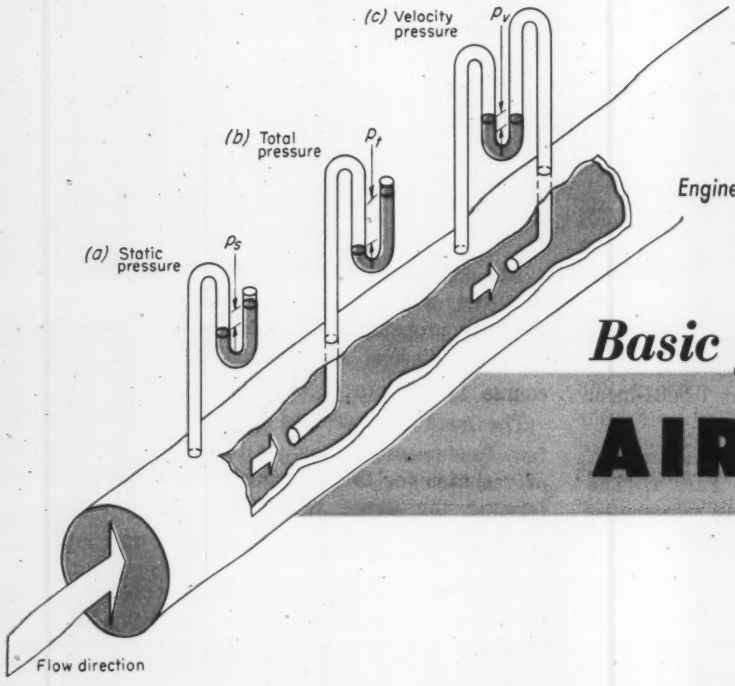
1. A function of normally distributed random variables is also normally distributed.
2. A function of rectangularly distributed random variables is approximately normal under certain conditions.

In the next and final part of this series some of the practical considerations of dimension control will be reviewed. The purely mathematical part of this subject, invaluable though it is, is merely a tool in the hands of the designer. The usefulness of this tool depends on a thorough understanding of the subject as a whole.

They Say . . .

"The ways by which scientists have learned, through a gradual evolution, to form sound judgments are exerting great influence on human affairs. This influence would become far wider and more beneficial, however, if these scientific methods could play a greater role in the education of everybody, including scientists themselves."—JOEL H. HILDEBRAND, *president, American Chemical Society*

Fig. 1—Measurement of air-duct pressures.



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Basic factors in AIR-CIRCUIT

MATCHING impeller and duct performance is the crux of the air-circuit design problem. Whether for a packaged air conditioner or a plant ventilating system, this design step ensures the air-handling compatibility of impeller and ducting. Generally, the matching problem is considered solved when the static pressure losses in the air duct—at design volume flow rate—are just made up by the pressure generated in the impeller unit.

As shown in this article, measure of the performance of a duct system is given by its system resistance curve, which shows duct static-pressure drop as a function of volume flow rate. Performance of impellers is given by similar pressure-flow plots. Intersections of such families of curves on a combined performance chart establish points of operation for an impeller-duct system.

As a guide to impeller selection, this article also gives a summary of the physical and air-handling characteristics of the basic impeller types. These characteristics are related to the specific requirements of the common air-moving systems in use.

System Pressures: In general, pressures discussed in this article are referenced to atmospheric pressure; that is, they are gage pressures.

Static pressure p_s is defined as the compressive unit force existing in a fluid and represents potential energy. It exists in air at rest or in motion and is the condition basically responsible for moving air against system resistance.

In the air circuits discussed in this article, pressure at any point does not vary substantially from atmospheric, and the effects of compressibility can therefore be neglected. For example, a pressure change of 10 in. of water (referred to atmospheric) is only 2.46 per cent of the standard atmospheric pressure of 407 in. of water. Since a static pressure of 10 in. of water is an extremely high pressure for conventional air circuits, the assumption of constant air density is justified.

Velocity pressure p_v, also normally expressed in inches of water, is produced by the velocity of fluid flow and represents kinetic energy. Total

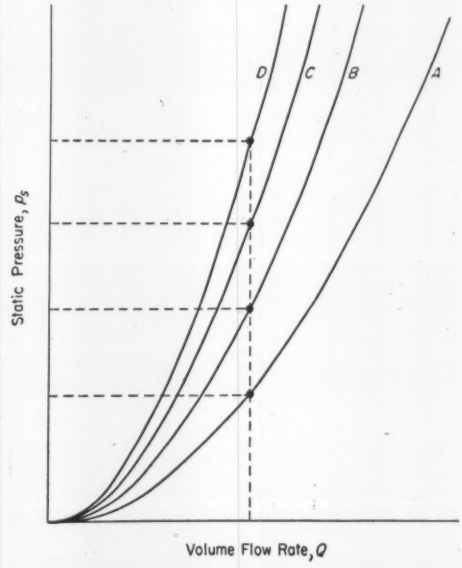


Fig. 2—Variation of system static pressure with volume flow rate. Resistances of ducts *A* to *D* vary because of different lengths, roughness, etc.

DESIGN

pressure-flow relations
system resistance
impeller-duct matching
impeller types and performance

pressure p_t in an air-moving system is the sum of static and velocity pressure, or $p_t = p_s + p_v$. Total absolute pressure at any point is the sum of total pressure p_t and atmospheric pressure.

At standard air density, $\rho = 0.075$ lb per cu ft, velocity pressure (in. of water) is given by

$$p_v = \left(\frac{v}{4005}\right)^2 \qquad (1)$$

Since $Q = vA$, the required velocity pressure at any point in a system is fixed by the rate of air flow that must be maintained.

The sketches in Fig. 1 show methods for measuring static, total and velocity pressures; they are helpful in visualizing the physical nature of such pressures.

Static pressure is equal in all directions in still air. In moving air, it can be accurately measured with a manometer connected to a pressure tap that is flush with the inner wall of the duct, Fig. 1*a*.

Total pressure is measured by an open-ended probe facing directly into the air flow, Fig. 1*b*. Difference in the liquid levels in the manometer gives a measure of the total pressure value.

An instrument combining these two arrangements, Fig. 1*c*, gives velocity pressure as the difference between total and static pressures.

System Resistance: Air flow in a system is resisted by both duct friction and the energy dissipating effects of turbulence. In addition, the

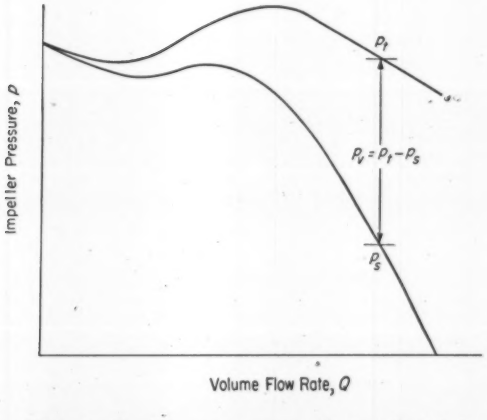


Fig. 3—Performance curves for typical impeller giving static and total pressures as functions of volume flow rate.

Nomenclature

- A = Area, sq ft
- K = Constant
- n = Impeller speed, rpm
- n_s = Specific impeller speed defined by Equation 4
- P_a = Energy delivered by impeller to the air stream, hp
- P_i = Mechanical power input to impeller, hp
- p_s = Static pressure, in. of water
- p_t = Total pressure, in. of water
- p_v = Velocity pressure, in. of water
- Q = Volume flow rate, cu ft per min
- v = Velocity, ft per min
- η = Impeller efficiency, per cent
- ρ = Air density, lb per cu ft

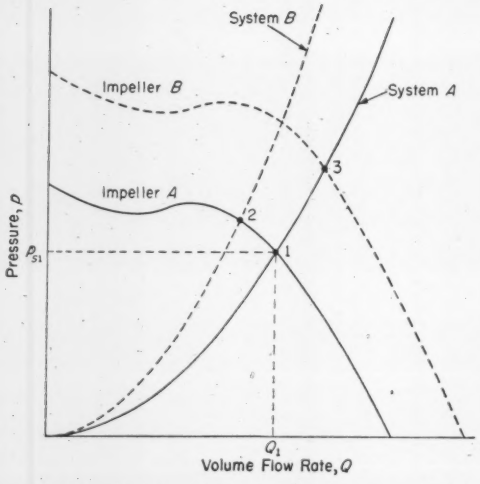


Fig. 4—Points of operation shown as intersections of impeller performance curves with system resistance curves.

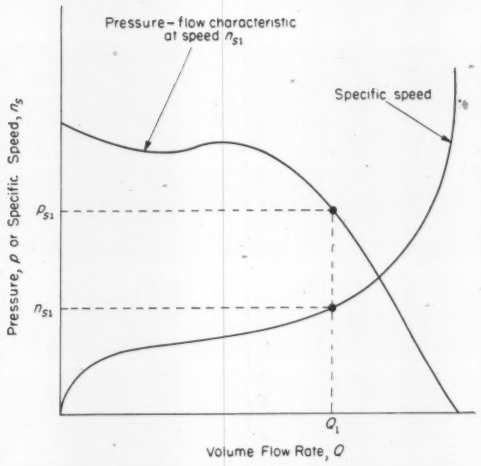


Fig. 5—Variation of specific impeller speed and static pressure with flow rate.

impeller must provide the velocity pressure necessary to accelerate the air to the velocity at which it enters the system. Duct friction and turbulence loss, in pressure loss per unit length, can be calculated as functions of fluid velocity by means of formulas and empirical data given in standard references and manufacturers' literature. By such means, friction losses are obtained for various combinations of duct diameters and relative smoothness, as well as for elbows (usually in per cent of velocity pressure), grills and noncircular ducts.

Total circuit loss is related to fluid velocity v by $p_s = Kv^x$, where K is a constant defining the system, and $x = 2$ is an acceptable approximation for most practical air circuits.

Total system resistance can then be expressed as the overall static pressure loss that corresponds to a particular fluid velocity and, therefore, to a particular velocity pressure. The air impeller must add this magnitude of static pressure to the system in order to maintain flow at a given fluid velocity. If too little pressure is generated by the impeller, velocity decreases; conversely, too much static pressure at the impeller increases velocity. In either case, specifications on volume flow rate are not satisfied.

In Fig. 2, curves are plotted giving the static pressures required to overcome system resistance as a function of flow Q (or velocity v). Since static pressure is approximately proportional to the square of fluid velocity, these representative curves have the form $p_s = KQ^2$. The four curves *A*, *B*, *C*, and *D* in Fig. 2 represent four different air-moving systems with increasing amounts of total system resistance. Thus, duct *D* may be smaller, rougher, longer or have more turns than ducts *A*, *B*, and *C* and therefore requires a higher static pressure to maintain a required flow rate.

Impeller Action: Any rotating air impeller adds kinetic energy to the air in an air-moving circuit. A portion of this kinetic energy is converted to potential energy (static pressure). In Fig. 3, the total pressure (upper curve) produced by a particular impeller as a function of Q represents the total energy available at the discharge of the impeller. A curve of p_s vs Q for any impeller generally varies from high to low pressures as the flow rate increases. There is a definite saddle or flattening in some range on all such curves, Fig. 3, as the impeller approaches a stall condition.

At the point of free flow, that is, when the impeller discharges into open space, total pressure consists entirely of velocity pressure. In this condition, velocity pressure is lost as the kinetic energy is converted into heat through turbulence.

The lower curve in Fig. 3 represents static pressure alone, and its intercept on the horizontal axis corresponds to the free-flow condition.

Duct and Impeller Matching: When an air-moving circuit and an air impeller are combined—for example, the system represented by curve *A* in Fig. 2 and the impeller in Fig. 3—it is quite evident that there is only one combination of static pressure and flow rate that satisfies both the requirements of the system and the capacity of the impeller.

In Fig. 4, where the performance curves for the system and impeller have been replotted, the matching condition occurs at the intersection, point 1, for the two curves. This point is known as the *point of operation* for the system. Flow rate Q and static pressure p_{s1} represent operating conditions for the impeller when it rotates at a given speed. When impeller *A* is combined with system *B*, however, the point of operation becomes point

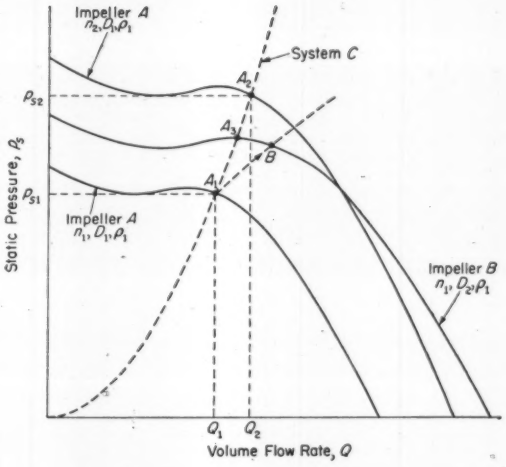


Fig. 6—Application of fan laws demonstrated by changes in impeller performance and points of operation as speed and size of impeller change.

2 instead of point 1. On the other hand, if impeller B is used in system A, the point of operation falls at point 3.

Power and Efficiency: Air horsepower P_a (either total or static) is the energy that is delivered by an impeller to an air-moving system and is given by

$$P_a = \frac{Qp}{6360} \qquad (2)$$

where p is either static pressure, p_s, or total pressure, p_t. The efficiency η of the impeller unit in per cent may be expressed as either static or total efficiency and is given by

$$\eta = \frac{P_a}{P_i} \times 100, \qquad (3)$$

where P_i = impeller input power.

When the impeller discharges into a plenum chamber, or into any section where the velocity head is dissipated in turbulence, static air horsepower and static efficiency should be used in Equations 2 and 3. When the discharge is into a smooth continuation of the impeller discharge, where the velocity head is not immediately dissipated, total air horsepower and total efficiency accurately represent performance of the system.

In a full-flow system—an air circulator, for example—air is discharged into a very large area and circulation is free. The static pressure is so small that it is usually assumed to be zero. A convenient way in which the designer can determine the relative performances of such circulating fans is to compare total efficiencies based on total air horsepower, corresponding in this case to velocity pressure alone. In most practical static-pressure applications, however, the reduction in velocity pressure from the full-flow value is of such magnitude that use of velocity pressure in evaluating impeller efficiency is not realistic. Static air horsepower and static efficiency, related to static pressure at the output of the air impeller, are most commonly applied.

Static efficiency is a very important factor since it is related directly to the cost of impller operation. Each type of air impeller has a maximum static efficiency which is obtained under specific operating conditions.

Specific Impeller Speed: A useful quantity to be considered in selecting impellers for optimum static efficiency is specific speed, given by the expression

$$n_s = \frac{n\sqrt{Q}}{p_s^{3/4}} \qquad (4)$$

For a particular type and size impeller rotating at a known speed, specific speed can be plotted as a function of Q, Fig. 5. A given impeller with fixed proportions has its peak static efficiency at a specific speed which is essentially independent of size. Therefore, after the specific speed required in any application is determined, it is possible to select the most efficient type of impeller by consulting charts that give values of n_s at which each impeller type operates most efficiently.

Impeller Selection: After the designer has ten-

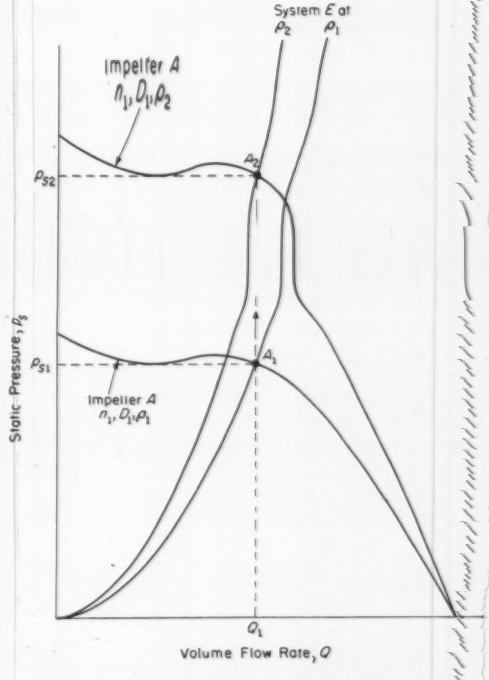


Fig. 7 — Application of the fan laws demonstrated by changes in impeller performance, system resistance and points of operation as density changes.

tatively chosen a number of impeller types, all of which satisfy requirements for Q, p_s and n, he makes the final selection on the basis of optimum static efficiency, available space and impeller cost. Several appropriate impellers may be eliminated because either size or shape or both are unacceptable. The relative static efficiencies and initial costs of the remaining impellers of acceptable sizes are evaluated in order to make a final selection. In considering all phases of design, the designer may logically select an impeller that operates at a relatively inefficient point on its operating curve (p_s vs Q) in order to obtain desirable advantages in size or proportion.

Fan Laws: Any point A_1 on the performance curve for impeller A in Fig. 6—corresponding to a known percentage of maximum flow and a known percentage of maximum pressure—is a point of rating for the impeller. The point of rating remains constant for a given impeller, or one geometrically similar to it, for different conditions of operation, as long as percentages of maximum flow and pressure remain constant. The fan law equations, Table 1, are relations which permit new values of Q and p_s at this point of rating to be computed for various changes in operating conditions.

Table 1—Fan Law Equations

Speed changes. Impeller type, size and air density remain fixed.

$$Q_2 = Q_1 \left(\frac{n_2}{n_1} \right) \quad (5)$$

$$p_{s2} = p_{s1} \left(\frac{n_2}{n_1} \right)^2 \quad (6)$$

$$Pi_2 = P_{i1} \left(\frac{n_2}{n_1} \right)^3 \quad (7)$$

Density changes. Impeller type, size and speed remain fixed.

$$Q_2 = Q_1 \quad (8)$$

$$p_{s2} = p_{s1} \left(\frac{\rho_2}{\rho_1} \right) \quad (9)$$

$$P_{i2} = P_{i1} \left(\frac{\rho_2}{\rho_1} \right) \quad (10)$$

Size changes. Impeller type, speed and density remain fixed; all dimensions change proportionately.

$$Q_2 = Q_1 \left(\frac{D_2}{D_1} \right)^3 \quad (11)$$

$$p_{s2} = p_{s1} \left(\frac{D_2}{D_1} \right)^2 \quad (12)$$

$$P_{i2} = P_{i1} \left(\frac{D_2}{D_1} \right)^5 \quad (13)$$

Width change (small changes only). Centrigufal impeller type, size, speed and density remain fixed.

$$Q_2 = Q_1 \frac{L_2}{L_1} \quad (14)$$

Application of the fan laws is demonstrated in Fig. 6. For example, with an increase in speed from n_1 to n_2, point A_1, as well as every other point on the curve, moves along a parabolic path to a new point such as A_2, giving a new performance curve for impeller A at speed n_2. For a proportional size change from D_1 to D_2 (constant speed and density), point A_1 moves along a different path to B. Moving many other points of rating similarly establishes the performance curve for impeller B.

It is a helpful coincidence that for speed changes the point of rating follows a parabolic path of the form $p_s = KQ^2$, which is also the system-resistance curve for a circuit defined by the constant K. Thus, if the original location of the point of rating is also the point of operation of the impeller in a system (point A_1 for impeller A at n_1 in system C), these computations give not only the new values of Q and p_s at the point of rating (when it has moved from A_1 to A_2), but they also give the new point of operation in that system (point A_2 for impeller A at n_2).

For density change ρ_1 to ρ_2 in Fig. 7, the fan laws state that there will be no change in Q and that static pressure will change proportionately from p_{s1} to p_{s2} as the point of rating shifts from point A_1 to point A_2. While the change in density has increased static pressure at the point of rating, it has also increased system resistance in the same proportion. The point of operation remains fixed at the point of rating.

When changes in parameters other than speed or density occur, such as a size change from D_1 to D_2 in Fig. 6, a new impeller performance curve must be computed (as for impeller B). A new point of operation is found at the intersection of the impeller curve and the system-resistance curve which, for impeller B in system C, is point A_3.

It should be recognized that the fan laws are

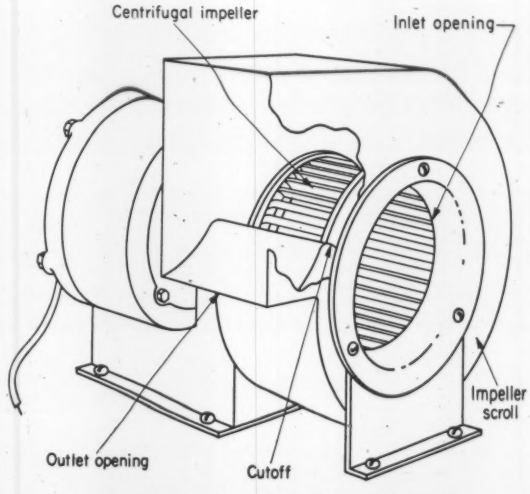


Fig. 8—Centrifugal-impeller components.

only approximations which become inaccurate with large changes in the parameters involved. With increases in speed or size, they generally underestimate performance and efficiency and overestimate input power.

Density Effects: Most published data on impeller performance are corrected to standard air density of 0.075 lb per cu ft at sea level (29.92 in. Hg barometric pressure), dry air, and 70 F. If the density in actual operation is significantly different from the standard, density should be converted to standard in order that published performance data may be used.

Air power required to move a given weight of air is minimum if the impeller is located at the point of greatest air density in the system. For example, a fan designed to move air in an electric heating system operates most efficiently when located at the input to the heater. At the heater output, density has decreased with the increased temperatures and, as shown in Equation 2, the higher flow requires more impeller power.

Conversion of actual density to standard in the use of published performance data is most common when impellers are being selected for use at high altitudes in airborne applications. For example, assume that an actual system is to be designed to deliver 100 cfm at $p_s = 1$, $P_i = 1$, and a density of 0.0375 lb per cu ft. From Equations 9 and 10, $p_s = 2$ and $P_i = 2$ are required to produce the same flow rate and speed at standard density of 0.075 lb per cu ft. Application requirements have been converted by this computation to the same basis as impeller performance data.

Centrifugal Impellers: In Fig. 8, a centrifugal impeller is shown in its housing. Air enters the center of the rotating impeller at the inlet, is accelerated by the blades, and is projected from the periphery of the impeller into the outlet duct. In addition to the type and size of impeller, the other important factors to be considered in selecting an impeller unit are inlet-duct approach area, size of inlet opening relative to the impeller, location and shape of the cutoff (which prevent recirculation of the air around the impeller), shape and dimensions of the scroll or impeller housing, and shape of the outlet to the air circuit.

The three basic blade types in centrifugal impellers are (1) forward-curved blades, (2) backward-curved blades and (3) radial blades. Representative examples of each are given in Fig. 9.

FORWARD-CURVED BLADES: A centrifugal impeller with forward-curved blades is primarily an impulse device because it is designed to accelerate air to a high velocity; its rotational speed is usually low compared to that of backward-curved impellers. The forward-curved type, known as a "volume" impeller, is much more commonly used than any other centrifugal type because it delivers the highest air volume for a given impeller size and speed. Conversion from velocity pressure to

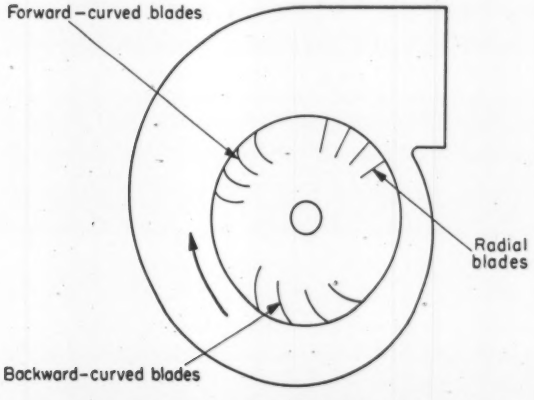


Fig. 9—Centrifugal-impeller blade shapes.

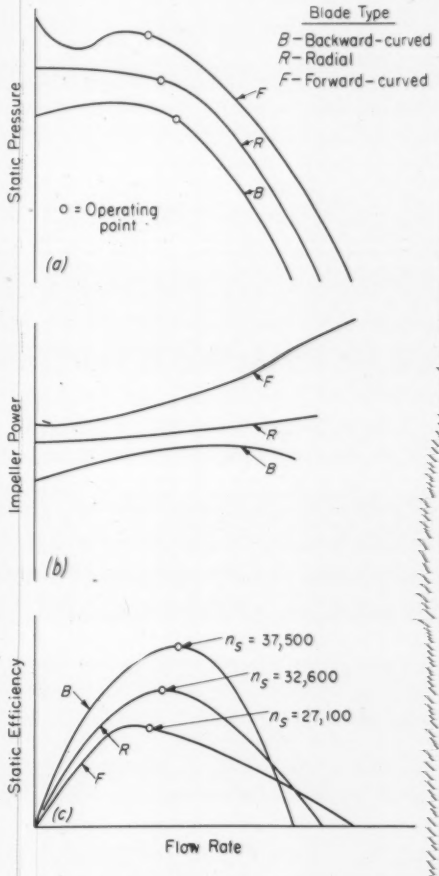


Fig. 10—Variation of (*a*) static pressure (*b*) power and (*c*) static efficiency for a centrifugal impeller with various blade shapes.

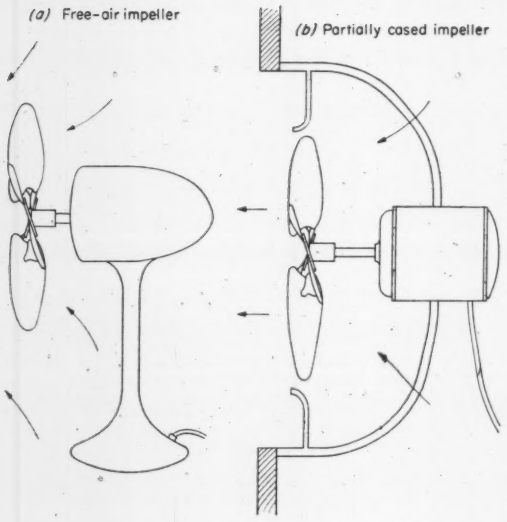


Fig. 11—Typical axial impellers without shrouds.

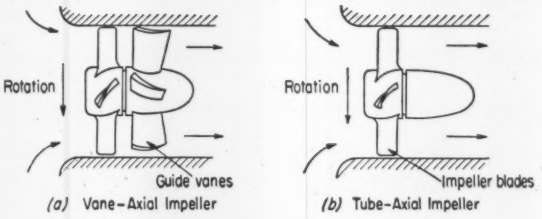


Fig. 12—Typical axial impellers with shrouds.

static pressure is accomplished in the scroll and outlet-duct diffuser.

BACKWARD-CURVED BLADES: A centrifugal impeller with backward-curved blades accomplishes more than half the pressure conversion in the between-blade passages. The backward-curved blade is very similar to an aircraft wing in its action on the air. Although flow velocity is increased, the blade serves primarily to lift and compress the air (velocity at the blade tips is outward with a high radial component). Since conversion to static pressure in the blade passages is very high, it is often possible for this type centrifugal impeller to operate at a reasonable efficiency without a housing.

The high static-pressure conversion obtained with backward-curved blades means that it is possible to minimize the inevitable energy losses in converting from velocity to static pressure in external diffusers, as is necessary with forward-curved blades. However, the gentle action of the backward-curved blades (as compared to the impulse action of the forward-curved blade) means that the impeller must operate at higher speeds in order to produce the same flow rate as an impeller of the same size with forward-curved blades.

A forward-curved impeller cannot be reversed and used as a backward-curved impeller because the intake edges of the blades are normally improperly shaped. In addition, different blade numbers and proportions are used with backward-curved blades in order to achieve optimum efficiency. Note the differences in blade camber for the forward-curved and backward-curved blades in Fig. 9.

RADIAL BLADES: Blades of centrifugal impellers with radial air discharge, Fig. 9, are simply a boundary shape between forward-curved and backward-curved blades. Straight radial blades are often used because they are simple to manufacture and can sustain high centrifugal loads.

Centrifugal Impeller Performance: Static pressure, impeller horsepower and static efficiency are given as functions of flow rate in Fig. 10 for typical centrifugal impellers with backward-curved, forward-curved and straight radial blades. All impellers have the same width and diameter and are operating at the same speed and in the same housing. Note that, for a given flow rate, the impellers with forward-curved and backward-curved blades produce static pressures, Fig. 10*a*, above and below, respectively, those produced by the radial-bladed centrifugal impeller. The performance curve for the impeller with forward-curved blades is the only one which shows the typical saddle at high static pressures and low flow rates.

The shape of the impeller horsepower curve, Fig. 10*b* is also characteristic of the type of blade. The horsepower curve for the radial-bladed impeller increases almost linearly with increasing flow rates. For backward-curved blades, the horsepower curve is maximum between 50 and 75 per cent of full flow. Above that point, the static pressure drops sufficiently to produce a decrease in horsepower input. For forward-curved blades, the typical horsepower curve is almost linear but slightly concave upward.

In Fig. 10*c*, for all three types of blades, the peak static efficiency occurs very near maximum static pressure. There is a considerable overlap in the ranges of specific speed at which forward-curved and backward-curved centrifugal impellers are most efficiently operated.

Housing Configuration: For impellers with forward-curved blades, it is normal practice to design the width of the housing moderately close to impeller width to conserve space, weight and materials. For backward-curved blades, on the other hand, housing width is usually made larger in relation to the impeller width; that is, the gap between impeller edge and housing is larger. Tests have shown that slight changes in housing width have negligible effect on the static efficiency of a given impeller, but have considerable effect on performance (magnitude of p_s at a given Q).

Shape of the cut-off, the distance it projects into

the outlet, and its proximity to the impeller must be carefully considered. If it is too sharp or too close to the impeller, excessive noise can result; if it is too shallow, decreased pressure will produce pulsation in the flow.

The diameter of the housing inlet should equal or slightly exceed the diameter of the impeller inlet. If these two diameters are not properly matched, a pressure loss due to leakage or unstable operation may result.

Axial-Impeller Performance: An axial impeller is a device for moving a quantity of air or fluid against a resistance in a direction that is essentially axial. The impeller consists of a number of cambered blades mounted on a spider or hub at some predetermined angle with the plane of rotation. In terms of performance, axial impellers may be classified into three categories: free-air impellers, partially cased impellers, and ducted impellers.

FREE-AIR IMPELLERS: The free-air impeller is commonly called a room circulator, Fig. 11*a*, and has no housing or casing. Its primary purpose is to circulate the air within the space in which it operates. The rotational motion imparted to the air by a free-air impeller is not redirected. The impeller is operating with maximum kinetic energy or flow against negligible static-pressure resistance.

PARTIALLY CASED IMPELLERS: The partially cased impeller, Fig. 11*b*, often called a propeller fan, consists of an axial impeller mounted within an orifice. It is designed to move air from one enclosed space into another at low static pressure.

Occasionally a propeller fan is required to move air against a source of relatively high resistance. In a room air conditioner, for example, this source of resistance may be the condenser or the evaporator coils. The type of orifice and position of the impeller in the orifice have important effects on the efficiency and performance of a partially cased impeller.

DUCTED IMPELLERS: The ducted impeller, Fig. 12, is completely enclosed axially by a duct with diameter slightly larger than the impeller tip diameter. It may have stationary guide or straightening vanes (vane-axial impeller in Fig. 12*a*) or it may not (tube-axial impeller in Fig. 12*b*). The tube-axial impeller is simply an extension of the propeller fan which can provide improvements in flow quantity, pressure and efficiency, primarily due to reduced air leakage at the blade tips. Static pressures may be as high as 5 in. of water. Static efficiencies are in the range of 50 to 60 per cent at moderate pressures, as compared to maximum static efficiencies of 45 to 50 per cent with a propeller fan.

The air discharged from free-air, partially cased, and tube-axial impellers has a rotational motion which represents an undesirable dissipation of energy. The vane-axial impeller and guide vanes are designed to maintain primarily axial air flow at both the intake and discharge and thereby eliminate energy loss associated with radial-flow components. Static efficiencies as high as 75 per cent are possible at relatively high static pressures —up to 24 in. of water. Tip clearance, hub-to-diameter ratio and airfoil design are also important factors affecting the static pressures developed.

Ducted impellers may be used for either moving air from one enclosed space to another at moder-

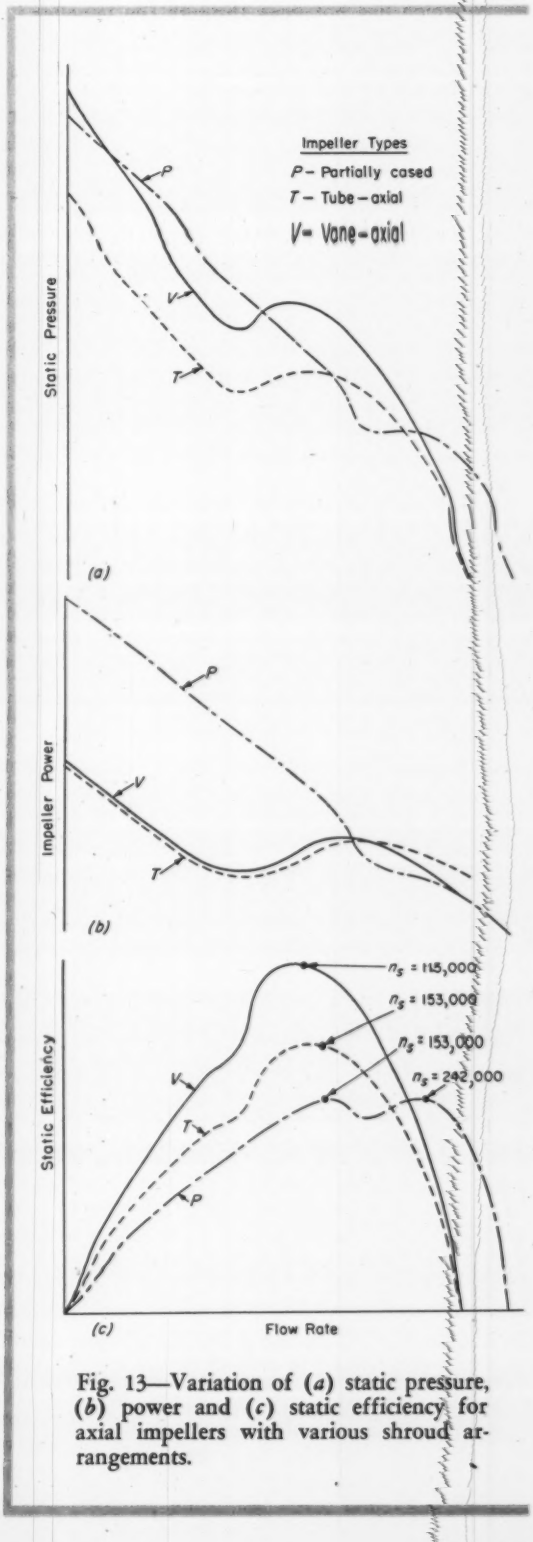


Fig. 13—Variation of (*a*) static pressure, (*b*) power and (*c*) static efficiency for axial impellers with various shroud arrangements.

ate to high pressures, or may act as an integral part of a closed flow system.

Free-air and Pressure Tests: The performance of a free-air impeller is most appropriately evaluated in the NEMA free-air test, which measures the circulated air in cfm through an arbitrary spatial plane on the outlet side of the impeller. A large proportion of the flow measured in this manner represents air drawn from surrounding space which has not gone through the impeller itself.

In a pressure test, on the other hand, pressure chambers are designed to measure air flow corresponding to various static-pressure differentials across the impeller. All the air flow measured in a pressure test must pass through the impeller.

Measured air flow for the same impeller will then always be larger in a free-air test than in a pressure test with a zero pressure differential. Measurements have shown that the free-air flow is from 10 per cent to 100 per cent greater. It is evident that free-air test data do not properly represent the performance of ducted impellers or even propeller fans in pressure applications.

Performance Curves for Axial Impellers: Static pressure, impeller horsepower and static efficiency are given as functions of flow rate in Fig. 13 for the typical partially cased, vane-axial and tube, axial impellers in Figs. 11*b*, 12*a*, and 12*b*. Identical impellers—same dimensions and number and shape of blades—are used in each case.

The pressure-flow characteristics in Fig. 13*a* are evidently quite similar for all three types of axial impellers, except that the stall recession for the partially cased impeller occurs closer to full flow. As flow decreases from the full-flow condition, each impeller exhibits a rising pressure characteristic to a peak beyond which the recession in the stall range occurs, followed by a sharp rise to shut-off.

The horsepower curves in Fig. 13*b* are very similar to the pressure curves. In the working range between full flow and the stall recession, however, the horsepower curves are comparatively flat, sloping downward to full flow.

Static efficiency for all three axial impellers in Fig. 13*c* is highest just before the stall recession. The specific speeds at maximum static efficiency for axial impellers range from 36,000 to 400,000, as compared to a range of 3000 to 60,000 for centrifugal impellers (Fig. 10*c*). Static efficiency is inherently low in the stall range. Therefore in order to insure satisfactory efficiency and quiet operation, the point of operation should be limited to those portions of the pressure curves preceding the stall recession. Partially cased impellers may occasionally be operated beyond the stall recession if their static efficiencies in that range are equivalent to that before the recession, as in Fig. 13*c*.

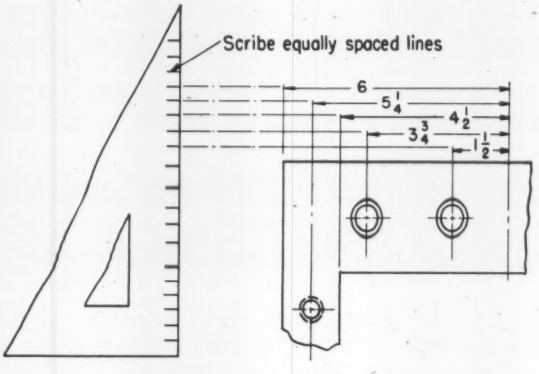
Design factors such as blade number, angle, length, curvature, thickness and hub diameter, while not usually under the control of the air-circuit designer, are important to impeller manufacturers as they strive for optimum static and structural efficiency in the desired range of operating conditions.

Impeller Choice: Performance curves in Figs. 10 and 13 for the centrifugal and axial impellers demonstrate the inherent operating characteristics of each type and help the designer make an intelligent selection of one or the other. Centrifugal impellers have their maximum static efficiencies at high static pressures and relatively low flow rates. Axial impellers, on the other hand, are most efficient when moving large volumes of air at lower pressures. There is, of course, an overlap in ranges. In terms of performance, then, the magnitude of the required static pressure is a helpful guide in selecting the impeller type. Other service conditions, however, can also affect the selection. For example, the space available may have considerable bearing on which flow inlet and outlet arrangement—centrifugal or axial—is most convenient in a particular application.

Tips and Techniques

Drawing Equally-Spaced Dimension Lines

DIMENSION lines can be equally spaced by scribing a triangle along any vertical side with equally spaced marks. Starting at the base di-



mension line, vertical witness lines are drawn to each succeeding mark up the scale. This leaves the ends of the witness lines spaced at equal intervals. Horizontal dimension lines are then drawn in by eye about 1/16-in. from the end of the witness lines, resulting in equally spaced dimension lines.—R. E. LANGE, *Oldsmobile Forge Plant, General Motors Corp., Lansing, Mich.*

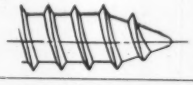
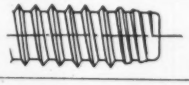
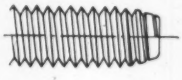
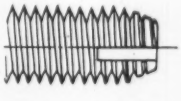
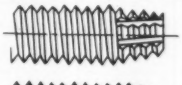
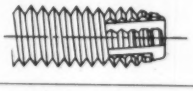
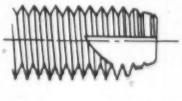
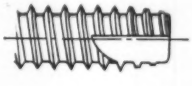
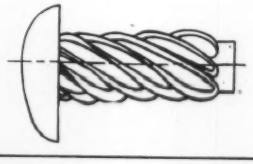
Correction

In the article, "Spring Alloys," May 31, 1956, one of the alloys discussed was described as "formerly known as Elgiloy." Elgiloy is not a defunct tradename; the alloy is currently available under that tradename from Elgin National Watch Co., Abrasives Div.

A design guide to selection of

Tapping Screws for Plastics

By Walton Yerger and Stuart Begg
Metallurgist *Chief Chemist*
American Screw Co.
Willimantic, Conn.

Tapping Screw Type	Letter Designation	
	Proposed ASA	Manufacturers
Thread Forming		
	A	A
	B	B,Z
	C	C
Thread Cutting		
	D	1
	F	F
	F	F
	T	23
	BT	25
Metallic Drive		
	U	U

IDEALLY suited for application with rigid plastic materials, tapping screws offer a range of thread forms to meet different fastening conditions. As an aid to screw selection and specification in design, the accompanying tables give recommendations for seven basic tapping screw types in specific rigid thermosetting and thermoplastic compositions.

For each material, the basic thread types are listed in order of preference. Both thread-forming and thread-cutting screws are included in the classification. Thread types covered here, along with the corresponding proposed American Standard* and present manufacturers' letter designations, are shown in Fig. 1. Type U metallic drive screws have not been included in the table listings. However, these screws are suitable for use with all of the plastic materials listed. They are forced into the material under pressure and provide a permanent fastening.

*From *Slotted and Recessed Head Tapping Screws and Metallic Drive Screws—ASA B18.6.4—*. This new standard, cosponsored by American Society of Mechanical Engineers and Society of Automotive Engineers, is now in tentative form, awaiting industry approval for general publication.

Fig. 1—Basic tapping screw types with corresponding proposed American Standard and present manufacturers' letter designations.

Tapping Screw Recommendations—Thermoplastic Materials

Material	Properties	Applications	Tapping Screw*
Acrylics (methyl methacrylate): CO, Fiberfil, Gering MMRW, Lucite, Plexiglas	Have ability to bend light. Fair to excellent machining. Low water absorption. Very good resistance to acids and alkalis. Continuous heat: Cast, 140-200 F; molded, 155-190 F.	Electroplating equipment, display boxes, refrigerator parts, aircraft cockpit enclosures, windows, models, display signs, lamp bases, instrument panels and parts, dials, name plates.	BT, T, B, A, D, F, C
Cellulose Acetate: Ampacet, Celanese, Fiberfil, Fibestos, Gering CA, Hercocel A, Hercocel W, Lumerith, Nixon C/A, Plastacele, Tenite CA	Tough. Good mechanical strength. Good resistance to water and some cleaning fluids. Good electrical insulation. Good machining. Continuous heat to 140-220 F.	Automotive hardware, machine and operative shields, closures, toys, models, drafting instruments and equipment, portable motor housings, handles.	BT, T, B, A, D, F, C
Cellulose Acetate Butyrate: Fiberfil, Gering CAB, Nixon CAB, Tenite CAB	Tough; high impact strength. Good dimensional stability. Low moisture resistance. High surface lustre. With inhibitors, have good resistance to outdoor weathering. Good machining characteristics. Continuous heat to 140-220 F.	Steering wheels, telephone housings, photographic equipment. (See cellulose acetate listing.)	BT, T, B, A, D, F, C
Cellulose Nitrate (pyroxylin): Nitron, Nixon C/N, Pyralin	Dimensionally stable. Very tough. Low water absorption. Resist dilute acids and alkalis. Excellent machining and fabrication. Continuous heat to 140 F.	Optical frames, pens, pencils, housing handles, frames, containers, toys, drawing instruments.	BT, T, B, A, D, F, C
Ethyl Cellulose: Ampacet, Ethocel, Gering EC, Hercocel E, Nixon E/C	High impact strength. High dimensional stability from −80 to 180 F. Good for severe outdoor exposure. Good machining qualities. Continuous heat to 115-185 F.	Refrigerator parts, flashlight cases, containers, tool handles, steering wheels, vacuum cleaner parts, communication equipment.	BT, T, B, A, D, F, C
Fluorocarbons (Polychlorotrifluoroethylene and Polytetrafluoroethylene): Bakelite CF3, Bakelite Fluorothene, Chemelec 300, Chemelec 500, Fiberfil, Fluoroflex C, Fluoroflex T, Fluoroplast, Gering KRW, Gering TRW, Kel-F, Polypenco-T, Teflon	Approximately the same for both material types, except in strength properties: Good to excellent machining. Excellent resistance to moisture and corrosive liquids. Tough; have high impact strength. Excellent dielectric properties. Self lubricating. Nonflammable. Not affected by sunlight. Continuous heat to 400-500 F.	Gaskets, housings and containers.	T, BT, D, F, C, B, A
Nylon: Fiberfil, Gering NRW, Nylasint, Nylatron, Nylon, Plaskon, Polypenco-N, Zytel	Excellent machining. Low water absorption. Good resistance to common solvents. Good chemical resistance. Continuous heat to 300 F.	Electrical devices, bearings, gears, gear couplings, cams, textile machinery parts, fishing reels, camera parts.	T, BT, D, F, C, B, A
Polyvinyl Chloride (rigid): Ace-Flex, Ace Riviclor, Agilide, Agilux, Ampacet, Bakelite, Boltaron, Denflex, Exon, Fiberfil, Geon, Gering, Lucoflex, Marvinol, Nixon, Opalon, Pliovic, Tygon, Vipla, Vygen	Excellent machining. High water resistance. Excellent corrosion resistance to 140 F. Continuous heat to 130-160 F.	Piping, flanges, filter parts, exhaust and ventilating equipment, ducts and storage tanks.	T, BT, D, F, C, B, A
Styrenes: Ace-Hide, Ampacet, Ampaloid, Ampcolite, Bakelite, Campco, Catalin, Cerex, Cycolac, Darex, Fiberfil, Fostarene, Gering PS, Gering PSX, Gilco, Goodrite 50, Helix, Koppers, Lustrex, Marbon 8000, Pliolite, Plio-Tuf, Resiston, Riji-Tuf, Stokoflex, Stokolite, Stycast, Styco, Styron, Textolite	Hard and rigid. Good dimensional stability. Relatively brittle except for high impact type. Have ability to bend light. Good electrical properties. Good to fair machining. Very low water absorption rate. Resist weak acids and weak and strong alkalis. Continuous heat 140-250 F; varies with type.	Cabinets, housings, refrigerator parts, chemical containers, display boxes, lighting fixtures, photographic and radio equipment, toys, clocks, film viewers, freezers, lawn mower wheels and fan parts.	BT, T, B, A, D, F, C

Tapping Screw Recommendations—Thermosetting Materials

Material	Properties	Applications	Tapping Screw*
Laminates: These materials consist of layers of various materials permanently bonded together by means of resins, such as, paper, fabric, wood and fibrous-glass laminates. Generally, the phenolic thermosetting types of resins are employed. Melamines, silicones, epoxy, polyesters and cellulosic resins can also be used.	In general: Properties vary with filler. Favorable strength-weight ratio. Good moisture resistance. Good chemical resistance. Will withstand 0-250 F.	Electrical appliances, panels and terminals, boards, table tops, gears, aircraft fuselages, wing tips, wing panels, caskets, luggage, air conditioning and heating duct systems.	BT, B, A, T, D, F, C
Lignin Resins (laminates): Benelex	Low production cost, good machining. Low water absorption. Continuous heat to 175 F.	Wallboard, toys, boxes.	BT, B, A, T, D, F, C
Melamines (molding): Fiberite, Melantine, Melmac, Permelite, Plaskon, Resimene	Good surface hardness and electrical properties. Excellent moisture resistance. Used with fillers to improve shock resistance and flexural strength. Resistant to common organic solvents, weak acids and alkalis. Fair to good machining, depending on filler. Continuous heat to 210-400 F.	Electrical and electronic instruments, tableware, trays, kitchenware, housings, furniture tops.	T, D, F, C, BT, B, A
Phenolics (molding): Bakelite, Co-Rd-Lite, Durez, Durite, Fiberfil, Fiberite, Fiberplast, GE, Heresite, Indur, Insurok, Kys-ite, Neillite, Plenco, Resinox, Rogers, Synvar PM, Textolite, Varcum	Hard and rigid. Good strength-weight ratio. Good wearing qualities. Application temperature 212-400 F depending on filler. Fair to good machining.	Clock, radio, TV and camera housings; containers and trays; electrical appliances and components; knobs, handles, radio parts and telephone equipment.	T, D, F, C, BT, B, A
Phenolics (casting): Catalin, Durez, Durite, GE, Gemstone, Haveg, Korez S, Lebec, Marblette, Nobellon, Plyophen, Resinox, Syncast, Synco, Synvaren	Same as for molded phenolics except for application temperature which is generally 160-250 F.	Clock, radio, TV and camera housings; desk articles, etc.; similar to molded phenolics.	T, D, F, C, BT, B, A
Phenolics (laminates): Aqualite, Capac, Celoron, Consoweld, Decarlite, Dilecto, Farlite, Formica, Hi-Den, Insurok, Lamicoid, Micarta, Nevamar, Norplex, Ohmoid, Panelyte, Phenolite, Phenrok, Pregwood, Resilyte, Ryertex, Spauldite, Synthane, Taylor, Tensilite, Textolite, Trevamo	Good strength-weight ratio (½ weight of aluminum). Good wearing. Excellent resistance to water and heat. Good chemical resistance. Fair to excellent machining.	Gears, casterwheels, radio parts, safety helmets, trays, insulation, refrigerator door liners and breaker strips.	BT, B, A, T, D, F, C
Polyesters (rigid casting resins): Atlac, Bakelite, Duolite, GE, Glidpol, Glykon, Helix, Hetron, Laminac, Marco, Paraplex, Plaskon, Pleogen, Polylite, Selectron, Sierracin, Stypol, Synvar V, Vibrin	Scratch resistant, good machining. Continuous heat to 250 F.	Telephone distributing frames and switches, switching centers, and other types of terminal plates.	T, D, F, BT, C, B, A
Polyesters (rigid molding compounds): Acme, Aropol, Bakelite, Cordopreg, Dapon, Diall, Fordadal, Glaskyd, Glastic, Plaskon, Plastrong, Pre-Impreg, and other fibrous-glass reinforced polyesters.	Strong, durable; high impact strength. Fair machining. Good solvent resistance. Mineral or putty types inert to acids. Continuous heat to 300-400 F, depending on filler.	Fishing rods, boat hulls, furniture, chemical containers, housings, structural parts for transportation equipment, refrigerator striker plates, automobile bodies, blowers for fan-cooled motors.	T, D, F, BT, C, B, A
Ureas: Beetle, Parswhit, Plaskon, Sylplast, Uramol	Excellent abrasion resistance. Excellent electrical properties. Good resistance to weak acids and alkalis. Good color stability. Continuous heat to 170 F. Fair machining.	Closures, appliance and electrical housings, containers and scale housings.	T, D, F, C, BT, B, A

*Listed in order of preference; based on proposed American Standard designations given in Fig. 1.

Numerical Coding Methods

. . . *for automatic machine controls*

By L. W. Herchenroeder

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Westinghouse Electric Corp.
East Pittsburgh, Pa.

VARIOUS functions involved in the numerical control of a hypothetical machine tool are shown in the block diagram, Fig. 1. Many systems do not have all of the functions listed, and the functions may not be in the same relative locations. This will affect the apparatus physically but is not important for the consideration of the basic aspects of numerical control.

Control information is transferred to the program storage medium in the form of punched cards or tape which, for relatively simple systems, may serve as the input to the machine controls. More complicated systems, such as those for contouring, usually require that the cards or tape be fed into a computer where the tool path, including cutter offset, is calculated and recorded in the primary storage medium. Interpolation is performed in the director which generates the secondary storage medium as the input to the actual machine control shown in dotted lines in Fig. 1.

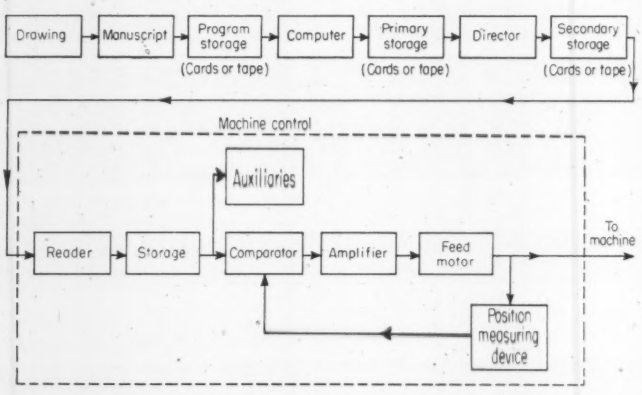

Fig. 1—Diagram showing relationship of components of a numerical control system.

As part of the machine control, a reader is required to extract information from the secondary storage medium. The data must be stored while being used by the control system; this storage may be accomplished by the reader itself or by internal storage in the machine control, according to the particular system.

At this point, position data is fed to the closed loop systems controlling machine motions. Since the actual machine motions are analog in nature while the data taken from the drawing is digital, a digital-to-analog conversion must take place at some point in the programming or in the control system. It may occur at the last possible point, at the machine motion itself, but in some systems con-

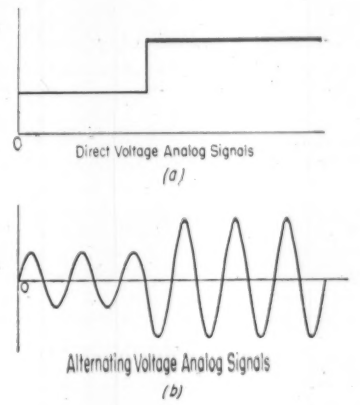

Fig. 2—Analog signals as direct and alternating voltages.

version is performed in the computer so that the data in the secondary storage is analog.

Analog Signals: Numerical control implies the use of information in numerical or digital form as contrasted to that in analog form. Digital information implies information in the form of pulses while analog information implies continuity. The distinction is more subtle than this, however, since analog information can be and often is presented in the form of pulses. This distinction is that digital signals are concerned only with a number of states of the signal—usually two—while analog signals are concerned with the value of some characteristic of the signal. Use of digital information involves counting, while use of analog information involves comparison of some characteristic of the signal to a standard.

To illustrate, a voltage signal is used to represent distance. In Fig. 2 both a direct voltage and an alternating voltage indicate a measure of distance in terms of voltage amplitude. For the alternating voltage, distance could have been made proportional to frequency or phase. All three indications represent analog signals. Fig. 3 shows pulse signals which are also analog in nature. In Fig. 3*a* the quantity of distance is proportional to height of the pulse and, in 3*b*, proportional to width of the pulse.

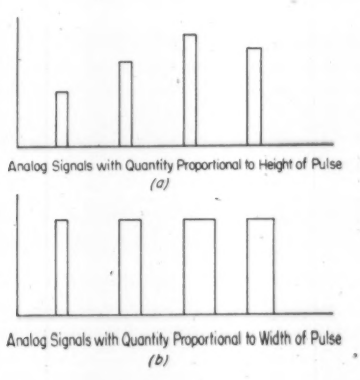
Analog Signals with Quantity Proportional to Height of Pulse
(a)
Analog Signals with Quantity Proportional to Width of Pulse
(b)

Fig. 3—Analog signals as pulses.

Digital Signals: Digital signals usually have two states. These states may be the presence or absence of a voltage or a voltage of one polarity as compared to a voltage of the opposite polarity. Within reasonable limits the magnitude or shape of the voltage pulse is not critical; the permissible variation depends on the components used in the particular control system. The lack of sensitivity to reasonable variations in the signal is the basis for the high inherent accuracy of digital systems.

Incremental and Absolute Systems: Numerical control systems may be classified as incremental or absolute systems depending on how the position data is handled. Incremental systems specify a new position in terms of the distance and direction from the last position. Absolute systems specify each position in terms of the distance from some arbitrary base. In an incremental system, an error in programming a given position will affect all succeeding positions. With the absolute system an error in programming is not passed on to succeeding positions. For incremental systems, power failure presents a problem in that the system may lose its memory of position, thus making it necessary to go back to some base point to pick up the program. However, the apparatus required for an incremental system is simpler and, therefore, has greater inherent economy and reliability than an absolute system.

Coding: Coding of numerical information, particularly in the primary storage medium, is currently receiving much attention from machine tool builders. Drawings and other design data generally use decimal notation for all numbers except those numbers less than one which are frequently expressed as fractions. However, fractions may be easily converted to decimals.

Decimal Coding: Since decimal numbers involve the use of ten digits, from zero to nine, to represent these digits mechanically requires that the mechanism have ten possible states. In desk type calculators, this is accomplished with gears having ten teeth, each of which represents one of the decimal digits. A comparable arrangement for punched cards or tape is to assign each of the decimal digits to one of ten positions and to indicate a decimal digit by punching a hole at that precise position, as shown in Fig. 4. A comparable arrangement for indicating decimal digits on magnetic tape or cards would be based on magnetization in one direction as equivalent to a punched hole, and no magnetization, or magnetization

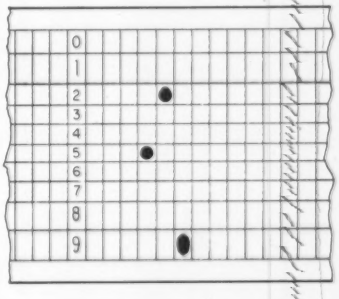

Fig. 4—Typical card or tape punched to indicate number 529 decimally.

in the opposite direction, as equivalent to no punched hole.

This plan has the advantage that the operator can easily tell what number has been punched, but also has a disadvantage in that it is inefficient in making use of the full information capacity of cards or tape and control equipment.

Binary Coding: Cards and tape —as well as such control components as relays, electronic tubes, magnetic and semiconductor devices—lend themselves readily to a two-state type of operation. This suggests the desirability of using numerical information in the binary rather than decimal form. In the binary system only two digits, zero and one, may be arranged to represent any particular number. Table 1 shows how identical numbers are expressed in both systems, binary and decimal. Binary coding for an arbitrarily chosen number, 529, is shown in Fig. 5. It can be seen that while ten channels are used in each of Figs. 4 and 5, the binary coding to represent 529 requires only one column while three columns are required for the decimal coding. Actually, however, the three columns of Fig. 4 can be used to represent all numbers, from zero through 999, while the single column in Fig. 5 has the capacity to represent the numbers from zero to 1023. As a practical disadvantage, however, it is virtually impossible for an individual to recognize by inspection the decimal equivalent of a binary number of any magnitude; in general, it is necessary to have a table of values, a pad and pencil, or a desk calculator to make this conversion. Further, when large numbers are involved it is difficult to transcribe binary numbers without error because of the monotony experienced when working with zeros and ones.

Table 1—Equivalent Numbers, in Decimal and Binary Form

Decimal Notation	Binary Notation
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
etc.	etc.
529	1000010001

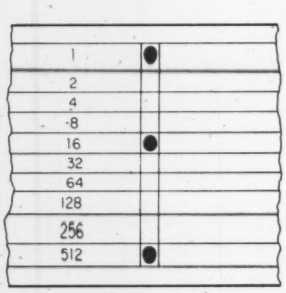

Fig. 5—Binary coding for 529.

Coded Decimal Notation: As a compromise between decimal and binary coding, coded decimal notation has most of the advantages of both and few of their disadvantages. In binary notation, the minimum number of binary digits that can be used to represent "ten" is four. Accordingly there is a first inclination to use the first ten binary numbers. This is known as the 8421 code and is illustrated in Table 2 and Fig. 6. Note that binary representations for 10 to 15 are not used.

For decimal numbers larger than nine, each of the decimal digits is represented by the proper combination of four binary digits, as illustrated for the number 529 in Table 2. The 8421 code is weighted; that is, a definite decimal value is associated with the "ones" in each of the four positions. By adding the weights associated with the "ones" in a particular coded number, the decimal value can be obtained. Fig. 6 shows that the number 529 in the 8421 code requires four rows and three columns, for a total of 12 possible hole positions. This compares with ten holes for the binary code in Fig. 5 and 30 holes for the straight decimal code in Fig. 4. Thus the economy of coded decimal notation approaches that of the straight binary code and considerably exceeds that of straight decimal notation. Furthermore, the readability of weighted decimal codes is superior to that of the straight binary code and compares favorably with the straight decimal code. Decimal digits represented can be obtained easily by adding the weights associated with the holes. An added advantage is that operators quickly develop the ability to recognize on sight the value of the numbers represented.

Table 2—Decimal Equivalents for 8421 Code

Decimal Notation	Coded Decimal Notation
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
etc.	etc.
529	0101 0010 1001

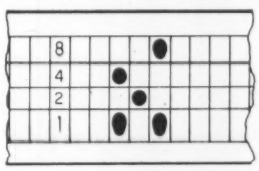

Fig. 6—Coding for 529 in "8421" code.

The 8421 code is not the only code that can be used; in fact, there are over 70 million ways in which the ten decimal digits can be represented by four binary digits. Even though only 17 of this 70 million are positive weighted codes, codes which are not weighted and those employing more than

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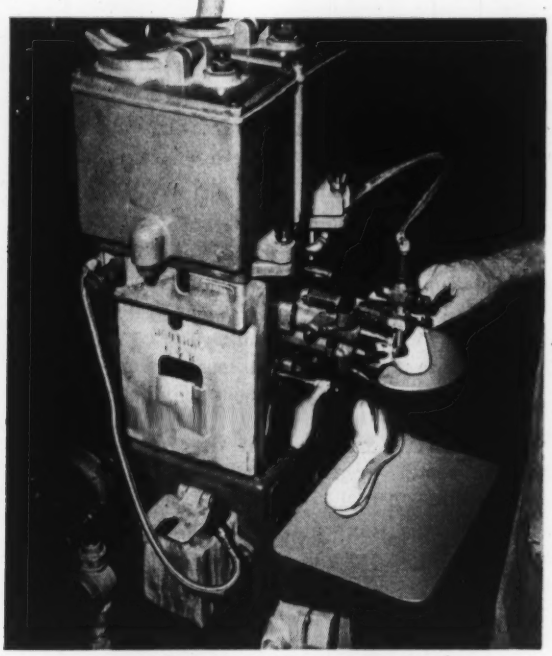

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—ITEM 542—

four binary digits are also of significance for numerical control. Among several decimal codes, the "2421" and "excess three" codes have the property of forming the nines complement by simple inversion; this is quite helpful in arithmetic operations. The biquinary code always has a "one" in one of the first two rows and a "one" in one of the last five rows. This characteristic is most useful for error checking.

Checking for errors is made possible through the inclusion of redundant information. For example, Fig. 7 shows the addition of a fifth row which is punched to insure that each column contains an odd number of holes. A single error will, therefore, result in an even number of signals per column. Through circuitry designed to register odd or even numbers of holes it is possible to indicate that an error has been made. By more elaborate use of redundant information it is possible to check more than one error and actually to locate and correct errors.

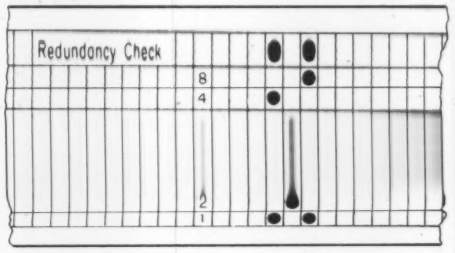

Fig. 7—Tape punched to enable redundancy check for 529 in 8421 code.

From a paper entitled "Some Basic Aspects of Numerical Machine Tool Control" presented at the 20th Annual Machine Tool Electrification Forum, sponsored by Westinghouse Electric Corp., in Buffalo, April, 1956.

Designing Bolts for Maximum Impact Strength

By John Love Jr.
General Electric Co.
Cincinnati, Ohio

and

O. A. Pringle
University of Missouri
Columbia, Mo.

IN WITHSTANDING impact loads, a machine element must be capable of absorbing a given amount of strain energy rather than merely resisting a certain applied force. Impact strength of a bolt or similar threaded fastener may be increased by reducing the cross-section area of its shank.

In a conventional bolt loaded in tension, stress in the shank is less than the stress in the threaded section because the shank cross-section area is greater than the cross-section area at the threads. A reduction in shank area would increase shank stress, shank elongation and total strain energy absorbed by the bolt. Maximum impact strength should be obtained with the bolt proportioned for equal stresses in the shank and threaded section. Further reduction in shank area would then decrease the impact resistance of the bolt. The ideal bolt for shock-loading would therefore seem to be one of uniform strength throughout.

In attempting to design such a threaded part, past practice has been to reduce the shank area to a value equal to or slightly less than the thread-root area. A shank area equal to 0.9 times the root area has been frequently recommended. This practice was based on two assumptions: first, that the thread root area was a sufficiently accurate measure of the static strength of the threaded section; and second, that stress concentration at the root of the threads weakened the threaded section during impact.

Lately, it has become customary to use the so-called mean or tensile-stress area as a more accurate measure of the static strength of the threaded section. This is a circular area computed from the mean of the pitch and minor diameters, and is a convenient approximation to the true area of a cross-section through the threads. It would seem reasonable in the future to correlate recommended shank areas with stress areas rather than root areas.

The effect of reduction of shank cross-section area on the tensile impact strength of 5/16, 3/8 and 7/16-in. steel bolts has been investigated experimentally. Low carbon 3/8-in. bolts with rolled threads absorbed maximum impact energy when the ratio of shank area to thread-root area was equal to 1.23. Heat-treated, medium-carbon 3/8-in. bolts absorbed maximum impact energy when the ratio of shank area to thread-root area was equal to 1.17 for shanks reduced by drilling or 1.12 for shanks reduced by turning. Results for other sizes were similar.

Thus, for maximum energy absorption the shank area should approximately equal the mean or tensile-stress area of the threads, with minor corrections to compensate for work-hardening due to thread rolling or surface oxidation resulting from heat-treatment.

From a paper entitled "The Influence of Shank Area on the Tensile Impact Strength of Bolts" presented at the ASME Annual Meeting in Chicago, November, 1955.

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For copies of any literature listed, circle Item Number on Yellow Card—page 19

Nuts & Locknuts

Technique of manufacture and proper installation of standard and special 12-Pointer and hexagonal nuts and Huglock and Marsden locknuts are covered in illustrated engineering data brochure. Chart for calculating wrench torques is included. 24 pages. National Machine Products Co.

—Circle ITEM 401

Precision Roller Bearings

Various Multirol, Camrol and Guiderol precision roller bearings have their sizes, capacities and mounting details given in comprehensive illustrated handbook H-54A. Line drawings show internal construction. The various seal combinations available are described. 58 pages. McGill Mfg. Co., Bearing Div.

—Circle ITEM 402

Investment Casting

Design data outlined in Haynes' Investment-Casting booklet cover physical, mechanical and chemical properties of 26 investment-casting alloys. Booklet offers hints on when this casting process would solve design and production problems. Photos show company facilities. 40 pages. Haynes Stellite Co.

—Circle ITEM 403

Fastener Catalog

Revised catalog covering standard Unbrako fasteners gives sizes and specifications on socket head cap screws, square head set screws, stripper bolts, flat head socket cap screws, button head socket cap screws, socket head dryseal pressure plugs, dowel pins and socket screw keys. 30 pages. Standard Pressed Steel Co.

—Circle ITEM 404

Variable Resistors

File-size chart giving electrical and mechanical characteristics of variable composition resistors illustrates and specifies over 18 basic single and dual-section controls. Possible modifications available on each control are also shown. Stackpole Carbon Co., Electronic Components. Div.

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Alumina Ceramics

Outstanding performance of AlSiMag alumina ceramics at high temperatures and frequencies is outlined in illustrated bulletin 562. Properties of some of the frequently used high strength and hardness materials are charted. 4 pages. American Lava Corp.

—Circle ITEM 406

Hub Mounting Device

The "Gripspring," a new device for mounting hubs on shafts without splines or keyways, is subject and title of this folder. Unit consists of two solid metallic rings that convert axial force into a large radial force between shaft and hub. 4 pages. U. S. Automatic Corp.

—Circle ITEM 407

Centrifugal Castings

Bulletins 150 through 154 provide information on range of machine parts and assemblies cast centrifugally from nonferrous metals; Meehanite, Ni-Resist and special iron alloys; and Meehanite metal bar stock. Last bulletin has chemical analysis chart on nonferrous alloys. Shenango-Penn Mold Co.

—Circle ITEM 408

Knitted Wire Products

Interesting fields of application for knitted stainless steel and nickel alloy wire are depicted in bulletin A-1. Included are filters, liquid entrainment separators, shock absorption cushions and electronic weather stripping. 8 pages. H. K. Porter Co., Alloy Metal Wire Div.

—Circle ITEM 409

Industrial Relays

Descriptions, including specifications and ordering information, are presented on Stromberg-Carlson industrial relays in bulletin T-5000. Fast and slow action, snap action, plug-in, alternating current and vibrator type relays, plus relay mountings and covers are described. 22 pages. Stromberg-Carlson Co.

—Circle ITEM 410

Power Take-Offs

Horsepower and torque capacities, side pull limitations and dimensions for all Twin Disc power take-offs are provided in bulletin 308. Information covers latest SP line with models ranging from 95 to 602 hp. 8 pages. Twin Disc Clutch Co.

—Circle ITEM 411

Jig & Fixture Components

Jig and fixture components pictured and described in this folder are a knob shoe assembly, ground thread studs, fixture keys, jig feet and rest buttons, jig leg plates, quarter-turn screws, toggle pads, head screws, angle plates, box jigs, mill fixture bases and torque screws. 6 pages. Standard Parts Co.

—Circle ITEM 412

Switches

All information necessary for ordering any Carling switch or accessory is provided in catalog C. Literature describes toggle, slide, rotary, push, grounding and special lever action switches, as well as outlets, caps and pilot lights. 12 pages. Carling Electric, Inc.

—Circle ITEM 413

V-Belts

Steel Cable V-belts in complete range of sizes and types are featured in bulletin V-1400-B20-P. Also described are other types and capacities of V-belts for single and multiple belt drive service. Tables give design and performance data. 6 pages. Worthington Corp.

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Variable Speed Transmissions

Developed for equipment using V-drives up to 10 hp, Maureymatic variable speed transmissions provide speed ranges up to 10 to 1. Drive data on various models are presented in illustrated catalog. 12 pages. Maurey Mfg. Co.

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Meter-Relays

Complete range of meter-relays are described and specified with general circuitry diagrams in catalog No. 4A. These units are indicating

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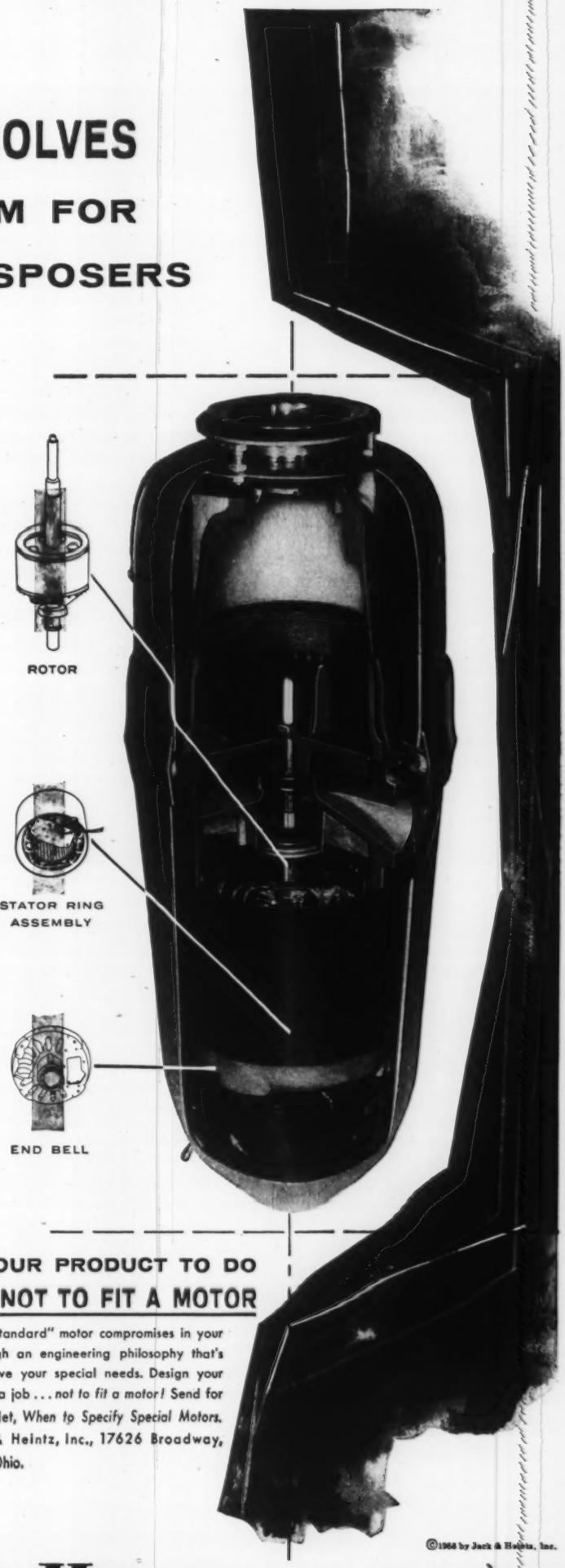

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Variable Speed Drives

In addition to providing selection tables for A, B, C and D section Texrope variable speed drives, booklet 20P50 gives data on design features, drive principles and horsepowers of drive belts. A speed range table shows variation in rpm when using two Vari-Pitch sheaves in combination. 44 pages. Allis-Chalmers Mfg. Co.

—Circle ITEM 417

Aircraft Bolts

"Let's Make a Bolt" is booklet which describes the manufacture of aircraft bolts from original wire stock to the finished product. Cold heading, bolt trimming, roll threading, heat treating, electroplating, Magnaflux inspection and final inspection are covered. 12 pages. Aero Supply Mfg. Co.

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Air-Hydraulic Controls

Speed King pilot-operated control valves are built to JIC specifications and are available in wide choice of options for air, hydraulic and vacuum control functions. Bulletin SK350 gives recommended service, pressure ranges, dimensions and condensed specifications. 6 - pages. Valvair Corp.

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DC Motors & Generators

Electrical and mechanical features, versatility, easy maintenance details, dimensions and ratings for new Kinamatic dc motors built to NEMA standards are covered in bulletin GEA-6355. Range is 1 to 150 hp. 12 pages. Kinamatic generators ranging from ¾ to 100 kw are illustrated and described in bulletin GEA-6461. 6 pages. General Electric Co.

—Circle ITEM 420

Power Transmission Devices

Illustrated "Power Transmission Equipment" catalog contains complete information on flexible couplings, variable speed pulleys, wide variable speed belts and sheaves, variable speed transmissions, motor bases and universal joints. Operating data tables aid in design engineering. 12 pages. Lovejoy Flexible Coupling Co.

—Circle ITEM 421

Airborne Hydraulic Valves

Design and application data on 17 different oil-hydraulic special and standard valves for airborne applications are detailed in bulletin A-5209. Chart shows types of pumps, accumulators, pressure controls, motors, directional controls and other components for airborne use. 8 pages. Vickers Inc.

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Welding Electrodes

"Weldirectory for Mild Steel and Low-Alloy High-Tensile Steels" is title of illustrated manual SB-1351. Physical properties, chemical composition, recommended welding procedures and other reference data are given for each iron powder and other welding electrodes. 28 pages. Lincoln Electric Co.

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Data Plotters

Two models of XY-plotters and recorders are designed for resistance inputs and direct current signal inputs respectively. Details of these precision instruments for rapid graphic depiction of one independent variable in terms of another are contained in bulletin. 8 pages. Librascope, Inc.

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Titanium

Available data on the corrosion resistance of titanium is contained in illustrated bulletin "Design Away Corrosion with Titanium." Various uses of titanium are discussed, and detailed table gives corrosion ratings with various acids, alkalies and chemicals. 8 pages. Mallory-Sharon Titanium Corp.

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Adhesives, Coatings, Sealers

Official U. S. Government specifications for a wide variety of adhesives, coatings and sealers are listed in folder No. 7. Each page is tabbed for easy reference. Cross references aid in correlating old and new specification numbers. 14 pages. Minnesota Mining & Mfg. Co.

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Small Thermostats

Mighty Mite thermostats with ratings to 10 amp on heater circuits are detailed in bulletin "Insured Product Performance." These compact factory-set units are small enough to be incorporated in motors, appliances, lab equipment and other electric apparatus. 4 pages. Mechanical Industries Production Co.

—Circle ITEM 427

Carbon Graphite Products

Available grades and characteristics of Purebon carbon graphite for mechanical applications are tabulated in catalog No. 55. Uses as bearing materials, seals, piston and packing rings, aircraft engine parts, molds and boats, valve seals and trolley wheels are discussed. 12 pages. Pure Carbon Co.

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Temperature Controls

Condensed design data on recording and indicating controls, electrical and mechanical nonindicating controls, thermometers, bulb installation accessories, thermal elements, process timers and gas pilots are covered by catalog CC. Types are offered for ranges of −30 to 1200° F. 8 pages. Partlow Corp.

—Circle ITEM 429

Brakes & Clutches

Electromagnetic principle utilized in line of electric brakes and clutches provides actuation time measured in milliseconds. Specifications for primary brakes, clutches, clutch-brakes, fractional horsepower RF brakes and other units are included. 8 pages. Warner Electric Brake & Clutch Co.

—Circle ITEM 430

Right Angle Gearmotor

Photographs and diagrams are used in booklet B-6579 to describe the type R right angle gearmotor for applications requiring 1 to 30 hp. Construction and operation are covered and a chart shows relationship between output torque capacity and total gear ratio. 4 pages. Westinghouse Electric Corp.

—Circle ITEM 431

Self-Tapping Inserts

Tap-Lok self-tapping bushing that is threaded inside and out and has cutting edges for installation in cored or drilled holes is subject of illustrated brochure. Various types, installation methods and other data are included. 12 pages. Groov-Pin Corp.

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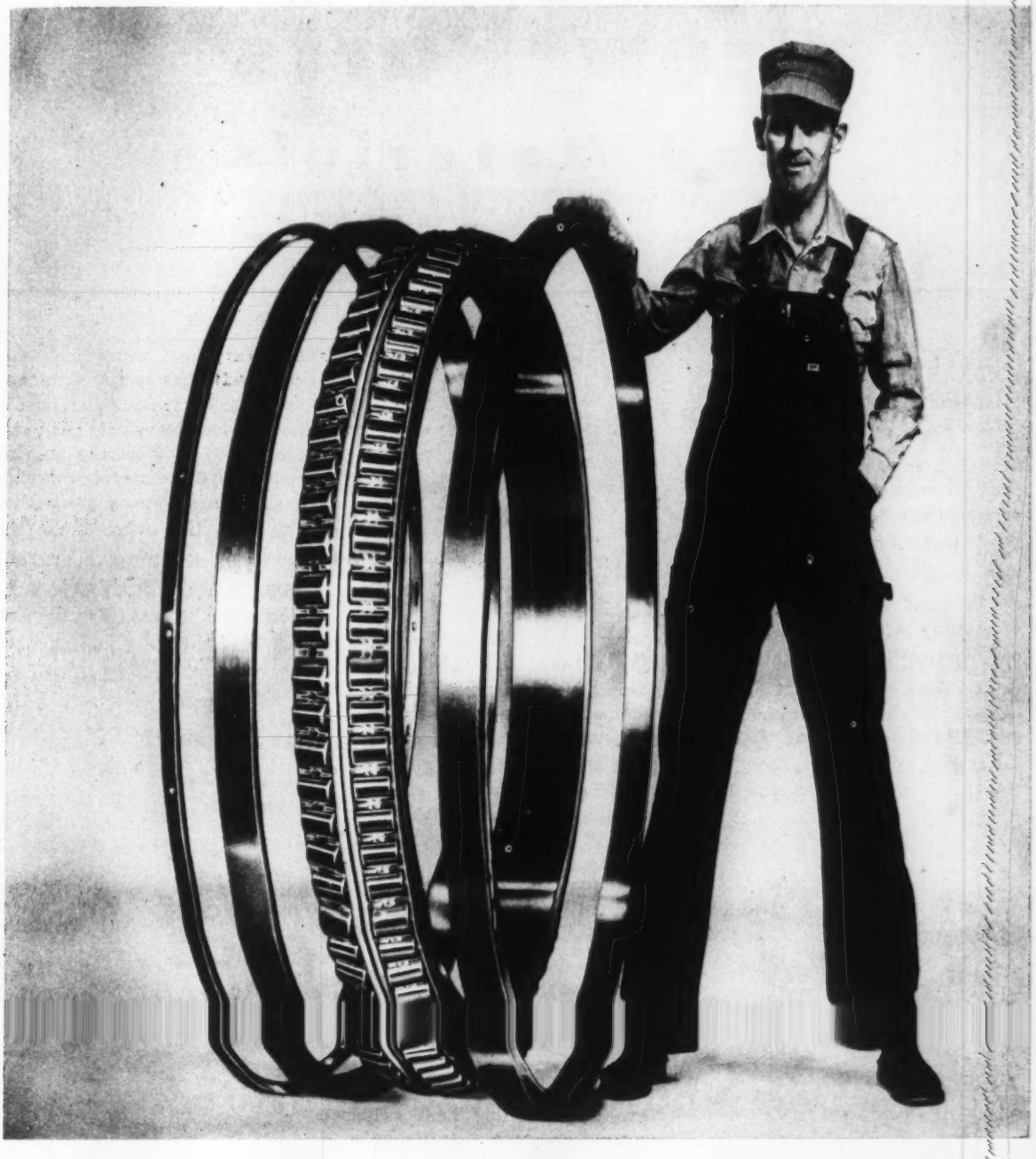

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New Parts and Materials

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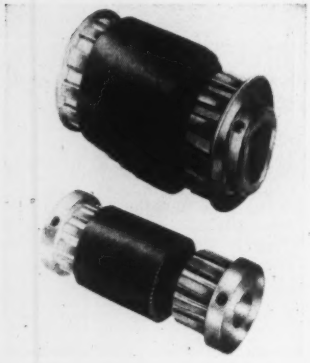
Flexible Couplings

for electric motors from 2½ to 25 hp

Gear-Grip couplings have high-capacity fiber reinforcement inbedded in heat and oil-resisting Neoprene. Power-transmiting strands absorb load pulsations and shock, providing torsional resilience with angles of twist up to 30 deg in the standard construction. Positive power transmission of the rated load is achieved by gear teeth on end castings fitted into matching teeth of the molded rubber tube section. The coupling is made in two basic hub



sizes with two, four or six-ply flexible elements to increase torque capacity for each hub size. The six combinations of hub size and flexible elements satisfy standard requirements for electric motors from 2½ to 25 hp. **Guardian Products Corp.,** Coupling Div., Dept. A-6, 1215 E. Second St., Michigan City, Ind.

—Circle ITEM 451

Miter Gear Boxes

available in ⅛, 3/16, and ¼-in. shaft sizes

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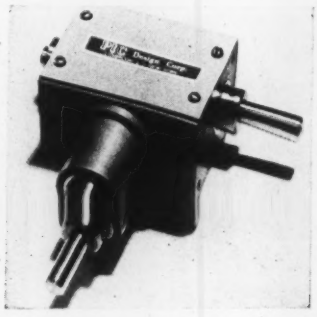

angle drives are required. The boxes have aluminum (chromic acid anodized) housings and covers, with stainless-steel ball bearings, shafts and collars. Miter gears are Type N matched pairs to minimize backlash. Units are available in ⅛, 3/16 and ¼-in. shaft sizes. **PIC Design Corp.,** 160 Atlantic Ave., Lynbrook, L. I., N. Y.

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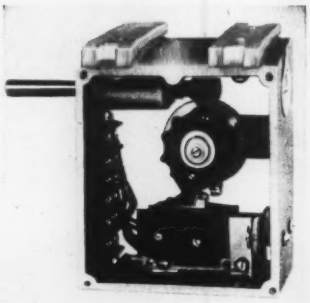
Heavy-duty rotating limit switch incorporates two single-pole, double - throw snap - action contact assemblies. Cast-aluminum housing with removable cover plate on each side of the switch provides complete accessibility for wiring. Long mechanical life is insured by the use of Oilite bearings on the input shaft

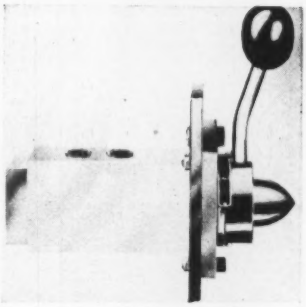


and heavy-duty worm and cam gears. Adjustments for cams and snap switches are easily accessible. The unit has heavy-duty pilot ratings to 480 v. Normally used as a pilot control to operate solenoids of magnetic reversing starters or contactors, the switch limits the travel of electrically operated doors, conveyors, hoists and similar mechanisms. **Furnas Electric Co.,** 1045 W. McKee St., Batavia, Ill.

—Circle ITEM 453

Flow Regulator

is adapted for panel mounting



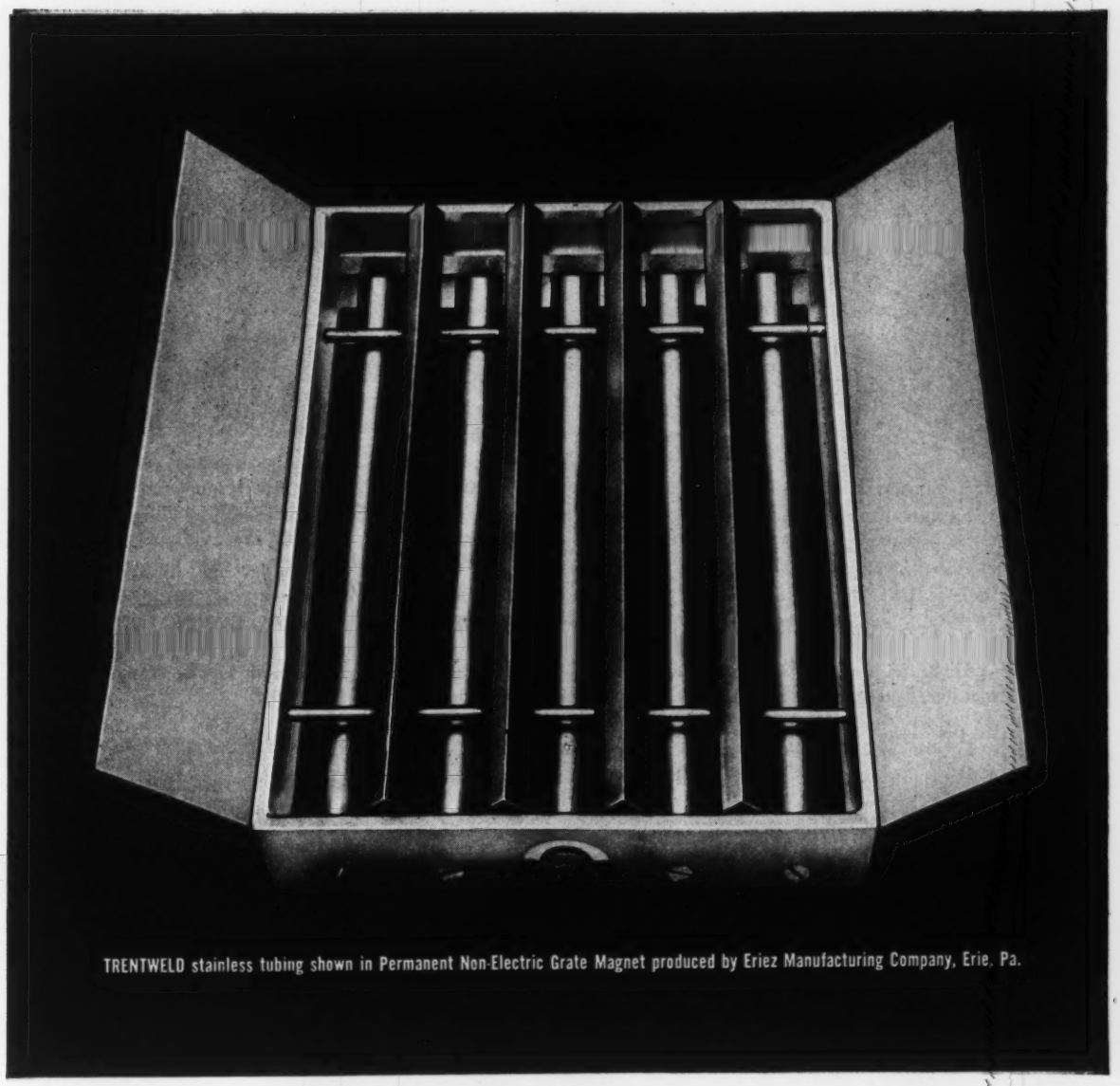
This adjustable flow regulator is applicable on any system requiring a variable adjustment of the flow rate over a wide operating range. Adapted for panel mounting, it has an aluminum body and internal parts of hardened steel. Adjustable control handle provides right or left hand rotation. **Waterman Engineering Co.,** 725 Custer Ave., Evanston, Ill.

—Circle ITEM 454

Valve

handles slurry-type or gritty fluids

Throttling action and tight closure of this "Sphincter Valve" is pro-



TRENTWELD stainless tubing shown in Permanent Non-Electric Grate Magnet produced by Eriez Manufacturing Company, Erie, Pa.

how TRENTWELD stainless tubing traps "tramp iron" in product flow...

As free-flowing products such as chemicals, grains, sugar or spices flow through this separator unit, large and small iron contamination is seized by powerful magnets and held firmly to the five stainless steel tubes.

This is a unit that's normally given long, hard use. That's why TRENTWELD stainless steel tubing is chosen to house the Alnico V magnetic elements. For stainless resists abrasion and corrosion . . . its smooth surface offers a minimum of resistance to product flow . . . and stainless is strong—lasts indefinitely. What's more, stainless is the easiest of metals to keep clean and sanitary.

And equally important to you is the fact that TRENTWELD is made by *tube mill specialists* —by the new, patented *Contour-Weld** Process. That means stainless pipe or tubing with a smoother I.D., free from any weld bead or undercut.

So when you need stainless or high-alloy pipe or tubing, make sure it's TRENTWELD. You can't buy better!

*Contour-Weld is the trade mark of the Trent Tube Company for its processes of welding pipe and tubing which is protected under U. S. Patent 2,716,692.

TRENTWELD

STAINLESS STEEL TUBING

TRENT TUBE COMPANY, GENERAL SALES OFFICES, EAST TROY, WISCONSIN (Subsidiary of CRUCIBLE STEEL COMPANY OF AMERICA)

—ITEM 545—

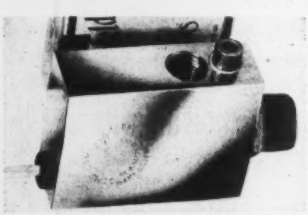
duced by axial compression of its rubber seat. Designed for slurries, erosive process flows or gritty fluids, the valve has been repeatedly cycled under 1000 psi water pressures without evidence of wear. An adjustable travel stop prevents excessive pressure on the seat. Parts exposed to the process fluid may be bronze, steel or stainless steel. Tubing sizes ⅜ and ¼-in. are available. **George W. Dahl Co. Inc.**, 430 High St., Bristol, R. I.

—Circle ITEM 455

Flow Indicator

detects flow as small as 1 gal per hr

Low capacity indicator, designated Model FI-900, operates on a pressure differential of less than ½-psi. Standard models are for use with ⅜-in. pipe and tube connections; ⅛ and ¼-in. connections are also available. The unit reliably detects flows as small as 1 gph through a pipe. The indicator can be in-



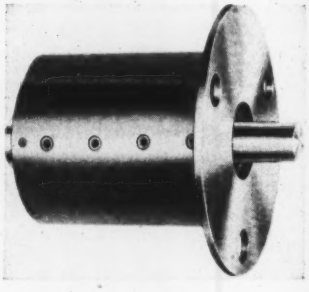
stalled on small, low-capacity circulating systems such as vent, lube and cooling lines. It can also be used as a bypass or indicating differential relief valve across filter systems or component equipment to indicate a bypass condition caused by clogging. The indicator has one basic moving part. Operation on standard models can be set at any point from 5 to 50 gph by external adjustment. Standard indicator is brass; bronze, aluminum, stainless steel and plastic are also available. **Gems Co.**, Wells Drive, Newington, Conn.

—Circle ITEM 456

Speed Reducers

have in-line shafts

Designated RD series, these in-line control shaft speed reducers are designed for adjustment and control of indicator or circuit functions of electronic and mechanical apparatus. Speed reduction is obtained from the differential-planetary rotation of precision ball bearings, providing smooth rotary motion. Completely enclosed, the units require no lubrication and use materials which comply with government specifications. They are available with six input-out-



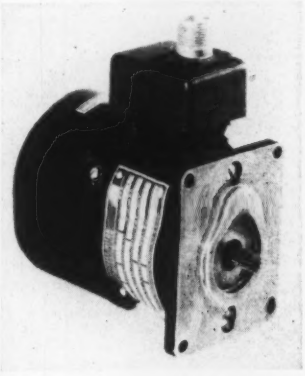
put ratios from approximately 2.5:1 to 20:1. **Jan Hardware Mfg. Co.**, 75 N. 11th St., Brooklyn 11, N. Y.

—Circle ITEM 457

Aircraft Pump Motor

confines gas-air mixture explosions

New line of continuous-duty explosion-proof motors (Type AK) for aircraft coolant pumps is available with ratings from 1/100 to 1/7 hp and speed ranges from 2800 to 14,000 rpm. Motor housing withstands and confines explosions of gasoline and air mixtures, or equivalent. It also effectively confines sparks and flames, preventing ignition of surrounding explosive mixtures. Cooling of totally enclosed motor is accomplished by an external fan that draws air through the shroud and forces it



over the housing. With a filter, radio interference developed is well within military limits. Special brushes are available with a minimum life of 500 hr at any altitude from sea level to 60,000 ft. **Westinghouse Electric Corp.**, Aircraft Equipment Dept., Wapakoneta Rd., Lima, O.

—Circle ITEM 458

Oil Seals

are applicable at temperatures to 250 F

Compounded from Goodyear Chemigum, a butadiene acrylonitrile elastomer, these oil seals are designed for general use in all moving machinery, such as automotive, farm implements, appliances, heavy-duty machinery and hydraulic systems. Seals are applicable at temperatures to 250 F with a wide range of commercial multiple-purpose oils, including hydraulic and detergent types and hydrocarbon test fluids. They meet SAE specification 110R-SX100-A & B through SX106-A & B and also R. I. Arsenal RJAPD 574, Class 1 through Class 3. Safe metal-to-metal press in bore is provided by the use of a positive rubber seal and single metal part on the outside diameter. The seals are available in standard sizes. **Yale Rubber Co.**, Sandusky, Mich.

—Circle ITEM 459

Air Motors

for missile applications

These air motors for missile application have a constant displacement rotary vane design. With the exception of blades and bearings, they are fabricated entirely of alu-

The Best

are the easiest

to get

in stock

in stock

in stock

mean faster deliveries from stock!

FOOTE BROS.
LINE-O-POWER SPEED REDUCERS

Standardized interchangeable gearing – by Foote Bros. – lets you specify and get the particular reducer you want, in the quantities you need, direct from stock! Duti-Rated Lifetime Gearing in a complete range of interchangeable sizes, ratios and capacities are stocked and ready for assembly. Capacities range up to 200 H. P., ratios to over 2700 to 1. Standard foot and flange type cast housings are stocked, too, for straight or right angle drives. The drives you want are assembled from stock components and shipped as soon as your order is received. For a complete index to the almost endless variety of Line-O-Power reducers immediately available, write for your copy of the Line-O-Power catalog today. See for yourself how you can get more for your drive dollar . . . faster!

This trademark stands for the finest industrial gearing made!

T. M. REG. U. S. PAT. OFF.

FOOTE BROS.

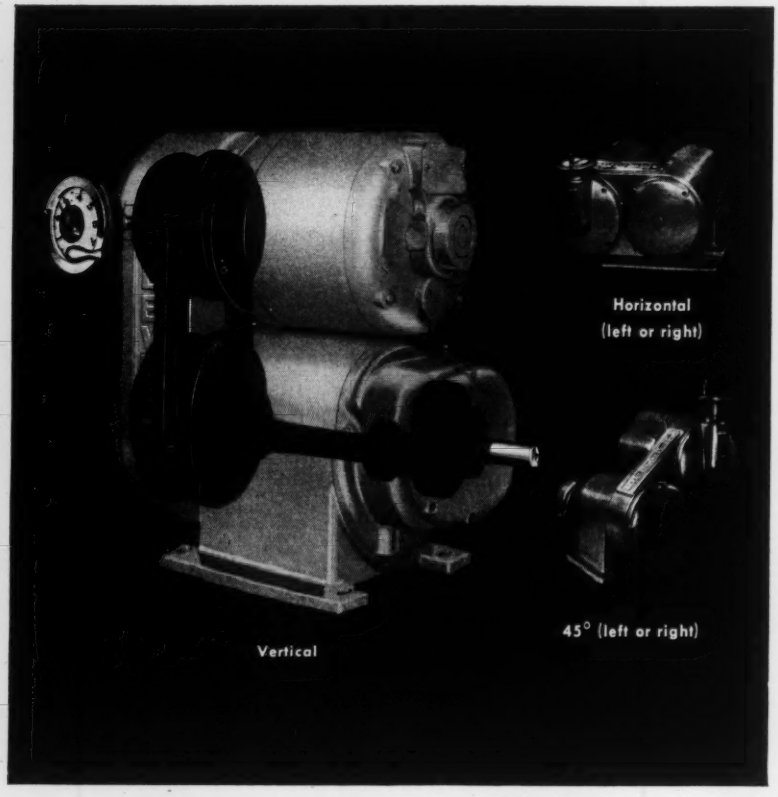
Better Power Transmission Through Better Gears

FOOTE BROS. GEAR AND MACHINE CORPORATION

4545 South Western Boulevard, Department O, Chicago 9, Illinois

—ITEM 546—

Variable Speed—Styled For Compact Machine Designs

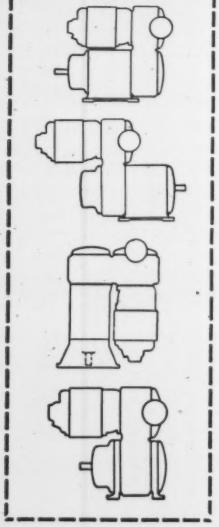


REEVES

FRACTIONAL *Vari-Speed* MOTODRIVE

WHERE DO YOU NEED THE OUTPUT SHAFT?

Motor side, control side, or vertical down



▶ REEVES fractional hp. Motodrive is a complete power package, engineered in over 100 assemblies to fit wherever your design calls for variable speed.

Choose from vertical, 45° or horizontal models in ¼ to 1 hp. . . . get stepless accurate speeds—within a 2:1 to 10:1 range—from as low as 3 rpm to a maximum of 4660 rpm.

Available in standard, weather resistant, totally enclosed or splash-proof enclosures; full range of manual or automatic controls.

REEVES Motodrive—the *right* speed for *every* need . . . in *any* place.

Write Dept. H23—M543 for ratings and dimensions

REEVES DIVISION • COLUMBUS, INDIANA

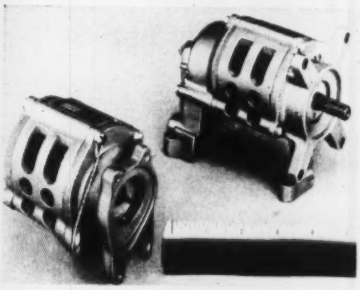
RELIANCE ELECTRIC AND ENGINEERING CO.

—ITEM 547—

For More Information Circle Item Number on Yellow Card—page 19

New Parts

minum and weigh 1½ lb. Units develop 2¾ hp per 100 psi inlet pressure, and perform satisfactorily with inlet pressure of 300 psi. Overall efficiency approaches 70 per cent at speeds between 3000 and 6000 rpm. The motors are qualified for missile applications



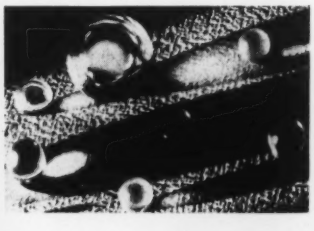
over an ambient range of −20 to 160 F and accelerations of 60 *g*. They withstand inlet gas temperatures in excess of 1000 F for as long as two minutes. In-line lubrication is not required. The motor on the right, used to run an alternator, contains a governor which maintains a constant speed within 2 per cent for load transients of 10 per cent. The governor regulates motor speed from regulated inlet pressures of 300 to 600 psi without the use of a reference spring, permitting the use of the motor with a 1000 F power source. Upon application of the supply pressure this motor will stabilize at regulated speed within 0.2 second. The motor on the left, without a governor, is presently used for hydraulic drive. **Bendix Aviation Corp.**, Pacific Div., 11600 Sherman Way, North Hollywood, Calif.

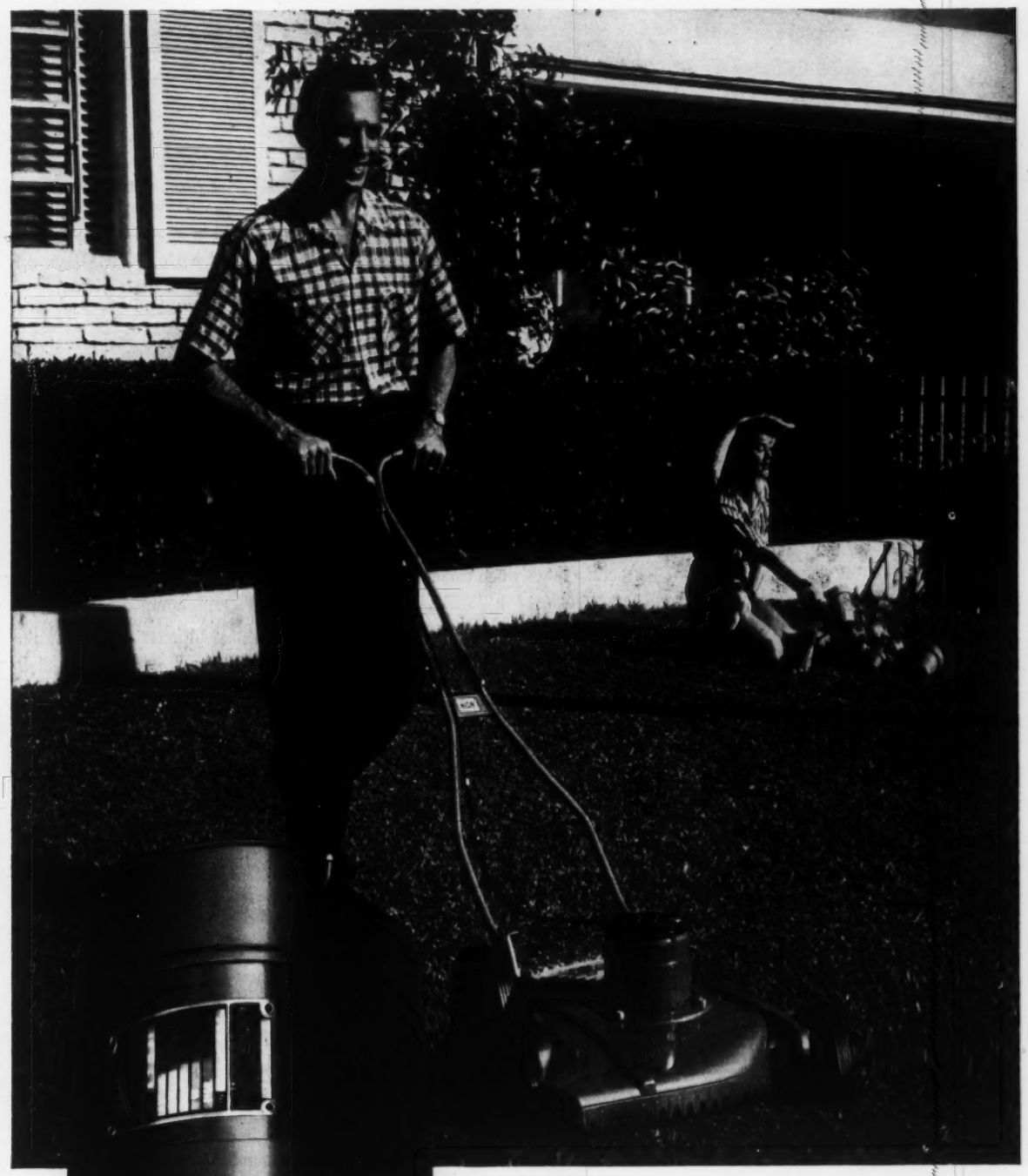
—Circle ITEM 460

Pyrex Balls

have diameters from 1/16 to 1 in.

These precision-ground Pyrex glass balls are nonconductive and unaffected by heat and cold. Light in weight, they are shock resistant





satisfied customers don't keep it a secret!

This man's bought a new way to do an old job . . . an electric power mower to cut his lawn. It's powered by a Packard Electric motor, in fact, and he's letting his neighbor in on its smooth, quiet, dependable performance. No, there's no secret here. There seldom is when an appliance is Packard-powered!

Packard Electric is an old hand at building satisfaction into motors. For over 39 years, Packard fractional horsepower electric motors have been delivering the kind of performance that makes for scenes like this. And scenes like this can't miss building sales and goodwill for appliance manufacturers.

GM GENERAL MOTORS

Packard

REG. U.S. PAT. OFF. TRADE MARK

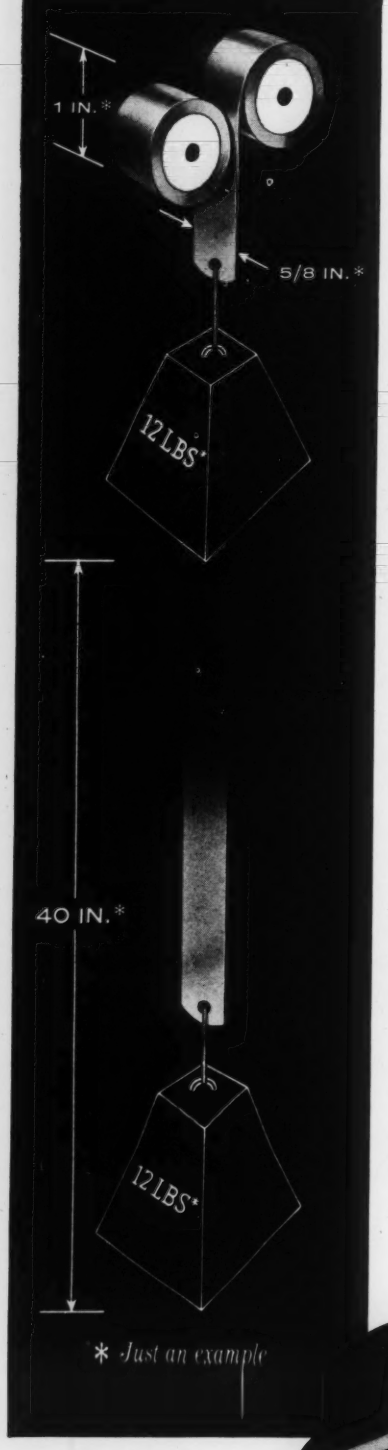
Packard Electric Division
General Motors, Warren, Ohio

—ITEM 548—

For More Information Circle Item Number on Yellow Card—page 19

BALANCE IT *with a*

NEG'ATOR® *constant-force spring*



NEG'ATOR is the name of a new kind of spring—the coiled-band spring that extends many times its original size without the increasing force common to conventional springs.

One of the natural uses of the NEG'ATOR Spring is counterbalancing without mass—vertically as illustrated, or horizontally. Using the NEG'ATOR Spring, the design engineer can eliminate dead weights or linkages and gain space, freedom of motion, reduced over-all weight, simplified assembly.

For example, each of the NEG'ATOR Extension Members used back-to-back in the illustration measures about 1 inch in diameter when coiled. They will counterbalance a 12 lb. weight over about 40 inches of travel. The only force required to move the weight is that required to overcome friction in the mechanism. There is no intercoil friction in the NEG'ATOR Spring.

NEG'ATOR Springs in extension or motor form are versatile in counterbalancing functions—are now being used to balance light tank floats in sensitive liquid-level indicators and fire doors and other heavy equipment. Extensions range to over 20 feet.

Used as an extension spring, a motor, band, clamp, or clip—this revolutionary new *constant-force* component upsets all previous spring principles, opens a whole new field of mechanical design by doing what springs have never done before.

These and other functions of Hunter NEG'ATOR constant-force springs are described in Bulletin 310N, "The Story of the NEG'ATOR Spring." Send for a copy.

HUNTER SPRING COMPANY

3 Spring Avenue, Lansdale, Pennsylvania

SPRINGS • STAMPINGS • TEST APPARATUS

—ITEM 549—

New Parts

and have a high load capacity. The balls are recommended for use with acids and liquids, in viscosity tests, developing films, and in flow meters, pumps, radio and electronic equipment where resistance to corrosives is required. Accuracy is maintained within ±0.001-in. on diameter and ±0.0005-in. on sphericity. The balls are available with diameters from 1/16 to 1 in. **Hartford Steel Ball Co. Inc.,** West Hartford, Conn.

—Circle ITEM 461

Axial Impeller

has low axial depth

Developed for applications where axial space is limited, such as in packaged air conditioners, type C-12-6 axial impeller has a 12 in. tip diameter and can be supplied

with either four or six blades. A wide range of pitches are available, and the fan comes with or without a slinger ring. Compared to former models, depth of this impeller model has been reduced, varying from 1 15/16 to 3 15/16 in., depending on the pitch. Fan hubs can be either rubber-bushed or solid. **Torrington Mfg. Co.,** Torrington, Conn.

—Circle ITEM 462

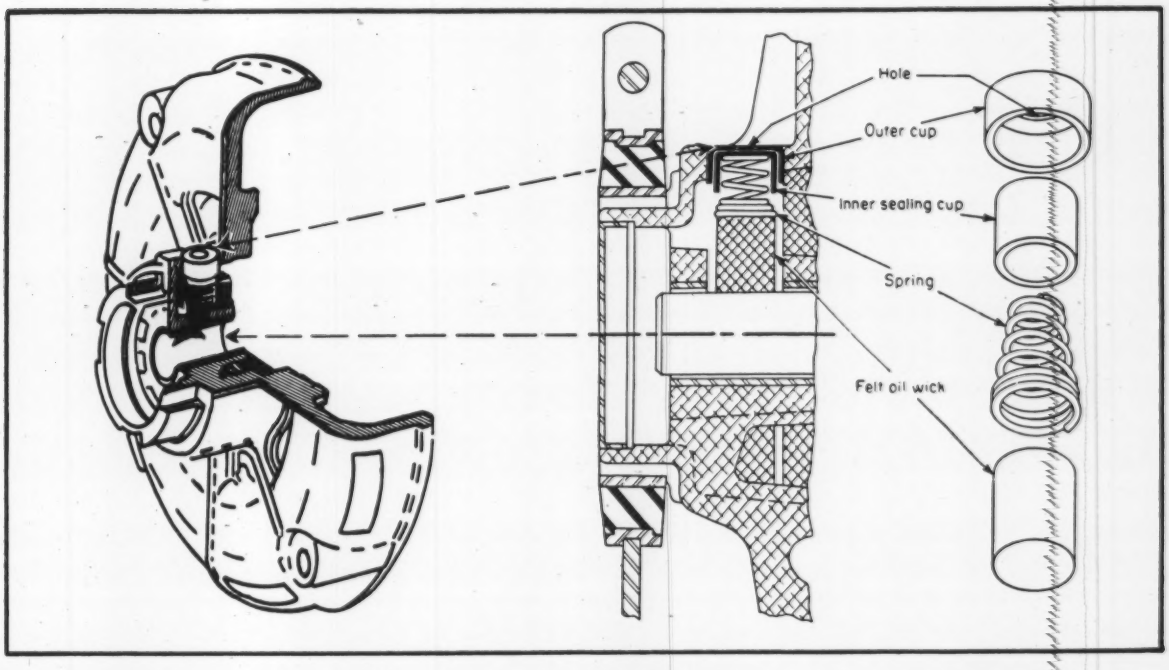
Heating Element

is adaptable to any mounting

This band type electric heating element is designed to apply heat directly to all surfaces where heat is required. It is very flexible and is available flat so that it can be shaped. The element has applications where heat and flexibility are required, such as in hot water heaters. It is furnished with clamp brackets and spring tension. Con-

Emerson-Electric engineering highlights

New, improved motor oiler assures positive, cleaner lubrication



A new-style oiler is a special feature included on many Emerson-Electric die-cast end-shield motors. It assures positive internal lubricating—also provides an added convenience in motor lubrication.

As shown in the illustration, the new oiler consists of three basic components—spring, retaining cup and oil-well cap. The spring performs two important functions:

First, it presses against a felt tongue which is part of the felt packing in the oil reservoir—the tongue extends through an opening in the sleeve bearing and makes direct contact with the shaft. By maintaining pressure against the tongue, proper lubrication is assured under all operating conditions.

Second, the spring holds the retaining cup in place against the oil-well cap; this prevents dirt and foreign matter from entering through the opening in the cap.

In addition, lubrication is simplified since pressure easily depresses the retaining cup, permitting oil to flow readily into the felt packing.

This is another of many Emerson Electric "highlight" engineering features that benefit designers and manufacturers of motor-driven appliances.

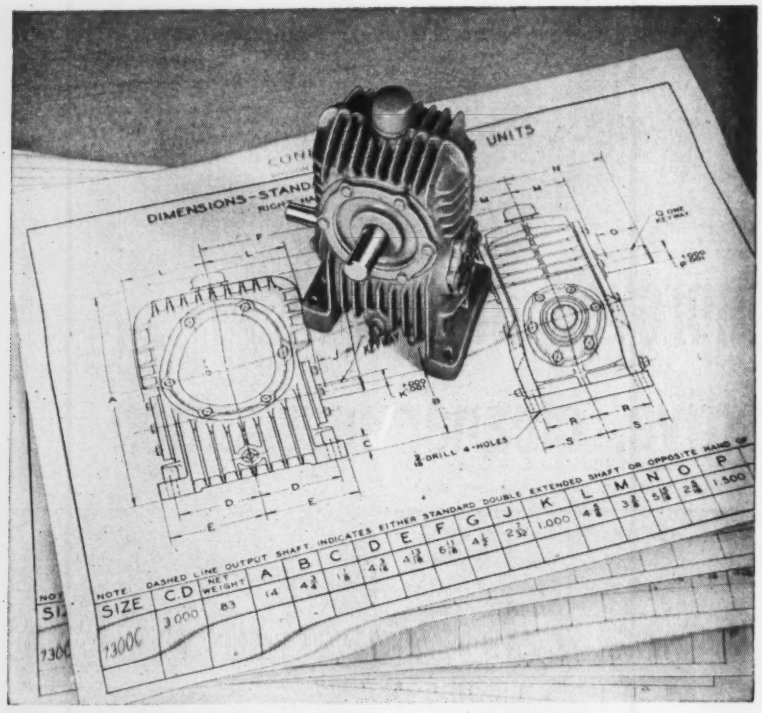
Call on Emerson-Electric motor-drive specialists

Recognized as a leader in equipment-drive motors for more than 60 years, Emerson-Electric specialists offer wide experience in all phases of motor-driven applications. You'll find their help valuable, whether you're designing or re-designing for performance and sales. Write for bulletin M-36. THE EMERSON ELECTRIC MFG. CO., ST. LOUIS 21, MISSOURI.

Emerson-Electric of St. Louis • Since 1890

BRANCHES: NEW YORK 7, N. Y., 11 Park Place • CHICAGO 23, ILL., 1623 S. Pulaski Road • SYRACUSE, N. Y., 209 Oakley Drive
PHILADELPHIA (Secane), PA., 868 Quince Lane • DETROIT 7, MICH., 1375 E. Jefferson Ave. • CLEVELAND 16, OHIO, 1580 Rockland Ave.
LOS ANGELES 42, CALIF., 5415 York Blvd. • DAVENPORT, IOWA, 617 Brady Street • CINCINNATI 11, OHIO, 2917 Ratterman Ave.

—ITEM 550—



DIMENSIONS ONLY TELL HALF THE STORY...

. . . about worm gear speed reducers. You've got to compare size with load capacity for the whole picture. Inside a Cone-Drive speed reducer you'll find the double-enveloping worm gear design that makes it the most efficient right-angle speed reducer available.

Take the standard 3" center distance unit above for example. Here are its Class I Service Ratings with a 5:1 reduction:

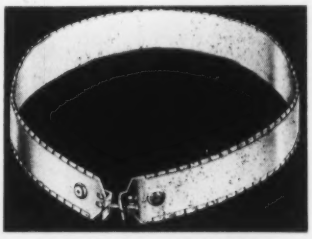
Worm RPM	100	200	300	580	720	870	1150	1750
Mech. HP	1.24	2.21	3.08	4.89	5.61	6.34	7.41	9.04
Thermal HP	1.24	2.21	3.08	4.20	4.62	5.10	6.00	7.80
Output Torque (inch-lbs.)	3340	3010	2830	2405	2250	2150	1940	1575

That's a lot of capacity for a unit that occupies less floor space than this magazine page. But it's typical of Cone-Drive speed reducers and gearsets. Complete details on this model in Bulletin 600-C. Other units to 800 HP and ratios to 4900:1.

CONE-DRIVE GEARS
Division, Michigan Tool Company
DOUBLE ENVELOPING GEAR SETS & SPEED REDUCERS
7171 E. McNichols Road • Detroit 12, Michigan

—ITEM 551—

New Parts



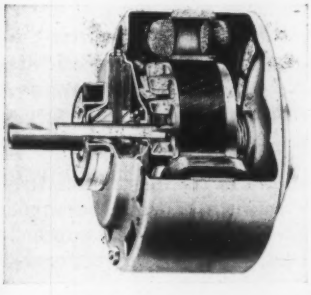
struction is mica insulation and nickel-chromium resistance wire in an aluminized steel case with screw type termination. The unit is available in a range of wattages, voltages, lengths and widths. **H. W. Tuttle & Co., Adrian, Mich.**

—Circle ITEM 463

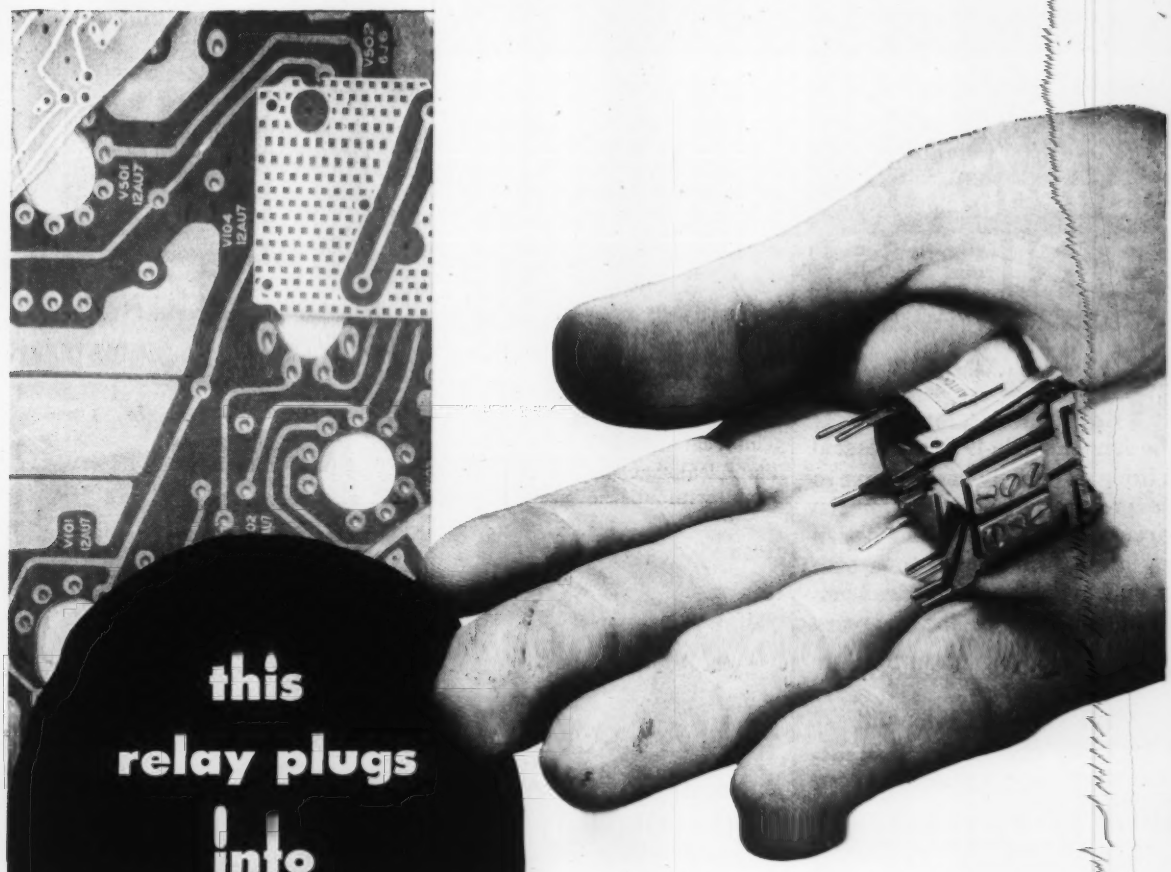
Fractional-Horsepower Motors

for air conditioners, heaters, blowers and fans

Shaded-pole and permanent-split capacitor 42-frame fractional horsepower motors have self-aligning bearings consisting of steel-backed, babbitt-lined sleeve bearings mounted in die-cast spherical cups. Initial oil supply in each bearing reservoir provides lubrication for five years of normal operation. Window in the bearing assures positive contact between wick and shaft, and grooves in the babbitted bearing provide a positive oil film between journal and bearing. Type FE shaded-pole motor is a constant

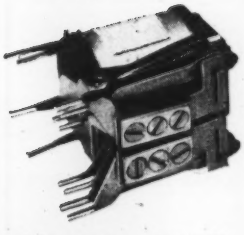


speed, switchless motor for low-power applications. It is rated 1/30 to ⅛-hp on 115 or 230 v, 60 cycles, at 1050 rpm. Type FLL permanent-split capacitor, constant speed switchless motor is rated 1/30 to ¼-hp on 115 or 230 v, 60 cycles, at 1075 rpm. Extended studs for end mounting or rubber rings for resilient mounting are provided. The motors are particularly applicable for room air con-



this relay plugs into printed circuits

. . . and runs up to 120 million operations without attention.



HELPFUL INFORMATION FOR THE TECHNICALLY MINDED . . .

Dimensions: Length, 1 ¾"; height, 1 5/16" to 1 ¾" (depending upon the number of contact springs); width, 1".

Operating Voltage: Up to 175 volts, dc, only.

Contact Spring Capacity: Maximum of 9 springs per pile-up.

Springs: Can be made of phosphor-bronze, "Bronco" metal, or other special purpose materials, as required.

A new stainless-steel armature bearing pin, a new sintered metal yoke, a new lubricating system for the armature—these features add up to 10 times the life of former relays. Automatic Electric Printed-Circuit Relays meet today's needs in automation, in computers, in any applications requiring utmost dependability.

Specially designed plug-in terminals are an integral part of the coil and of the contact springs. They make firm, tight, high conductivity connections with printed circuits—and may be permanently secured by using any recognized soldering technique.

Besides these features, you get efficient magnetic design, permanently welded contacts, "stay-put" contact springs and many other advantages found in all Automatic Electric relays. Save parts, assembly and wiring time by using printed circuits—and Automatic Electric Printed-Circuit Relays. For complete details, *write:* Automatic Electric Sales Corporation, 1033 West Van Buren Street (HAymarket 1-4300), Chicago 7, Illinois.

In Canada: Automatic Electric Sales (Canada) Ltd., Toronto. *Offices in principal cities.*

AUTOMATIC ELECTRIC

Originators of the dial telephone · Pioneers in automatic control

GENERAL TELEPHONE SYSTEM

—ITEM 552—

For More Information Circle Item Number on Yellow Card—page 19

COOPER ALLOY

CORPORATION BRIEFS

• Edited by GEORGE BLACK

DOUBLE-D REFINER

The Jones Double-D Refiner is said to bring an entirely new concept to the preparation of stock for the paper machine. Key to the design lies in the twin refining area with its double discs. For a more complete story ask for the February issue of Cooper Alloy NEWSCAST.

WHAT'S IN A TRADEMARK

Behind the Cooper Alloy trademark, cast or stamped into our stainless steel fittings, stands more than a quarter century of experience and the most complete production facilities in the industry. When you specify Cooper Alloy fittings you can be sure that every step from design to shipment is under the supervision of specialists. Look for the CA trademark before you buy . . . it is a sign of quality, experience and reliability.

DESIGN FEATURES FEATURED

Design features that have made the Cooper Alloy stainless steel valve the preferred valve for chemical processing are presented in the current issue of NEWSCAST. Diagrams and text combine to make a thorough presentation. Additional copies available on request.

NEW PUMP IN DEMAND

The new line of stainless steel rotary pumps announced by our Vanton Pump Division has taken the field by storm because it is the one (and only) pump of its kind without stuffing boxes or shaft seals. Bulletin VP561 gives the facts. Write for it today.

COOPER ALLOY

HILLSIDE, N.J.

—ITEM 553—

New Parts

ditioners, unit heaters and coolers, furnace blowers and window fans, and are guaranteed for five years. **Westinghouse Electric Corp.**, P. O. Box 2099, Pittsburgh 30, Pa.

—Circle ITEM 464

Seal Fitting

stops leaks at threaded connections

This seal fitting, designed to eliminate leaks at pipe-thread connections without the use of sealing

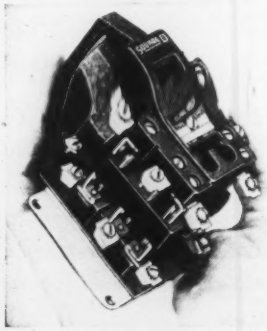
compounds, is applicable to all fluid lines, such as those carrying oil, water, air, steam or chemicals. Operating temperature range is −280 F through 500 F, and pressure rating is up to 3000 psi. It is especially recommended for use where leakproof operation is essential, where pipe compounds may impair circuit operation, and on fittings that require frequent take-down and re-assembly. Sizes are available to fit the majority of piping installations. **Flick-Reedy Corp.**, Tru-Seal Div., 2040 N. Hawthorne Ave., Melrose Park, Ill.

—Circle ITEM 465

Four-Pole Relay

for machine-tool applications

This four-pole machine tool relay, measuring only 2 13/16 in. by 3 11/16 in., is identified as class



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ADJUSTABLE-SPEED DRIVES

. . . covers all the basic methods of adjustable speed!

by

Robert C. Rodgers,

Leo F. Spector,

Keith A. Carlson

". . . the most comprehensive design guide on Adjustable-Speed Drives available *anywhere*"

ELECTRICAL

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MECHANICAL

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Here, in *one* book—148 pages, with 24 tables, 119 charts and 171 illustrations—is what the designer should know about adjustable speed. It contains the entire co-ordinated program of articles which appeared in MACHINE DESIGN on main drive and transmission types—electric-motor, slip-coupling methods, mechanical drives, and hydraulic drives.

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A *must* for your "working library". Use the handy form below and order your copies today! (Remittance enclosed with your order will speed the delivery of your copies.)

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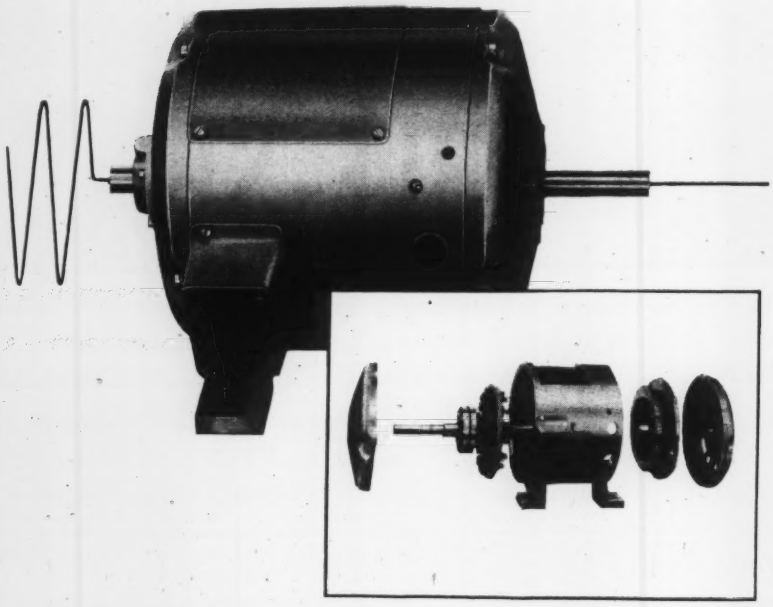
SPECIAL



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It's a rectifier because it supplies a DC speed control current from an AC alternator output. Special windings in the alternator impress a "revolving voltage" on a fixed commutator within the device. Rotating brushes collect this voltage, in proper synchronization, to deliver a DC output through two slip rings. This output is exactly proportional to the air gap flux of the alternator and is used to control the drive motor speed. This particular method was chosen for its exceptionally smooth, accurate control over a wide speed range from well below 100 rpm to above 4,000.

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Refer to Esco Catalog in section 4a/EL in Sweet's Product Design File, or write direct for general catalog No. 56PD. Why not also send us details on your special problem . . . we'll be glad to show you how we would go about solving it for you.

ESCO

ELECTRIC SPECIALTY CO.

179 South Street, Stamford, Conn.

New Parts

8501, type DO-42 and is a companion device to the two-pole type DO-22. Both relay models are rated 10 amp at 600 v. For mounting convenience and easy relay substitution where more poles are required, both relays have identical baseplates and can be mounted interchangeably. The molded coil is unbreakable, dimensionally stable and water and oil proof. All contacts are clearly visible for normal inspection and maintenance. **Square D Co.**, 4041 N. Richards St., Milwaukee 12, Wis.

—Circle ITEM 466

Packing Adapters

prolong service life of leather V-packings

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—Circle ITEM 467

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has torque rating of 10 oz-in. at 1 rpm

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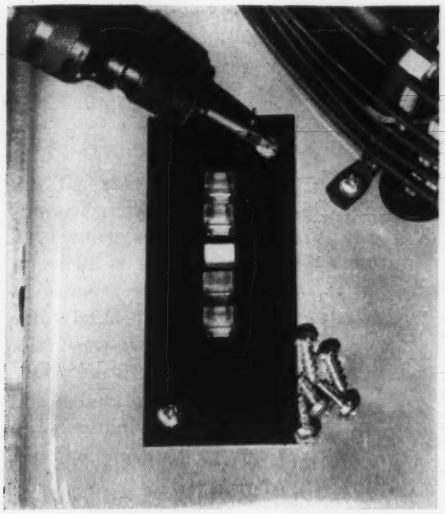
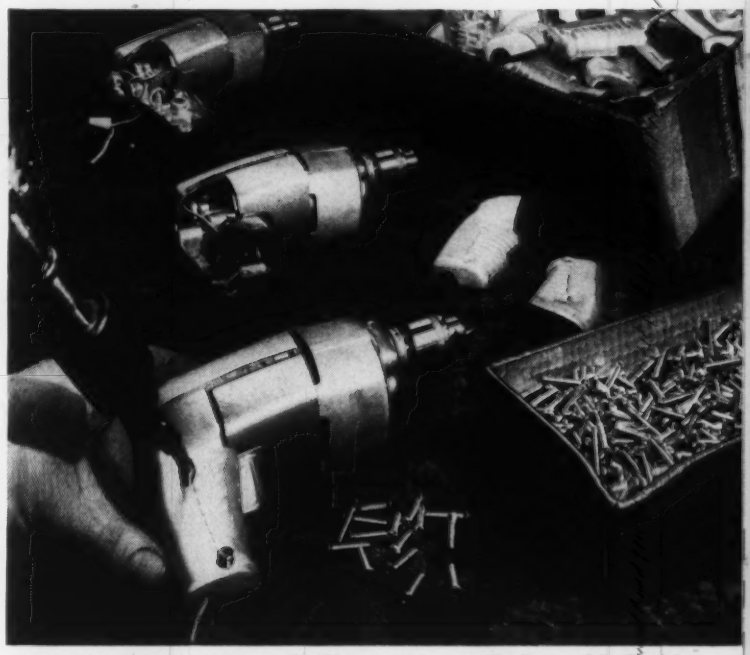
Three Users Give Many Reasons For Using

PHILLIPS CROSS RECESSED HEAD SCREWS



"WE USE PHILLIPS 100%," states Mr. R. A. Burket, Production Manager of McGraw Electric Co., Lonergan Manufacturing Division, "because experience has taught us that they are the fastest assembled in high-speed production line, hold their bond indefinitely under conditions involving constant vibration, and make a more decorative finished product."

SAMSONITE LUGGAGE uses Phillips Cross-Recessed-Head Screws to hold the alabaster plastic garment bar to metal hanger. "Not only are recessed head screws required in all our specification sheets, but Phillips is the one type specified throughout," says Mr. W. G. Axtell, Chief Engineer of Shwayder Brothers.



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MANUFACTURERS OF PHILLIPS CROSS-RECESSED-HEAD SCREWS

THE FASTENERS OF TODAY...

AND OF THE FUTURE

X marks the spot

the mark of extra quality

Pledged to highest standards...

The Phillips Screw manufacturers listed here cooperate to turn out a uniformly high standard of quality. As sponsors of the Phillips Cross-Recessed-Head Standards Committee they adhere to the established dimensional standards, gauges, and gauging methods which will best serve industry.

Members of Screw Research Association

American Screw Company • Atlantic Screw Works, Inc. • The Blake & Johnson Co. • Central Screw Company • Continental Screw Co. Elco Tool and Screw Corporation • Great Lakes Screw Corp. • The H. M. Harper Company • The Lamson & Sessions Company • National Lock Company • The National Screw & Manufacturing Company • Parker-Kalon Division, General American Transportation Corporation Pheoll Manufacturing Co. • Scovill Manufacturing Company • Shakeproof Division Illinois Tool Works • The Southington Hdwe. Mfg. Company • Sterling Bolt Company • Universal Screw Company • Wales-Beech Corporation

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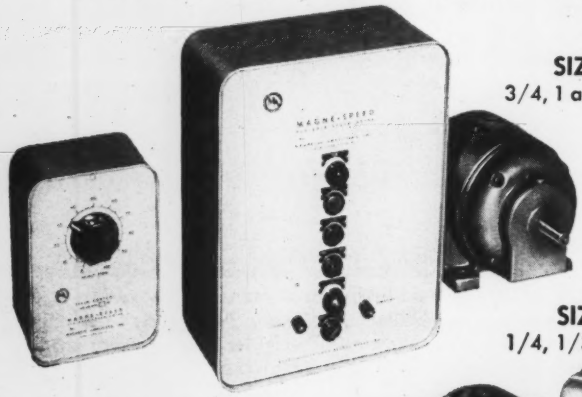
Magnetic Amplifiers · INC

—announces its new

VARIABLE SPEED DRIVE

MAGNE-SPEED*



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3/4, 1 and 1-1/2 HP

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1/4, 1/3 and 1/2 HP

Stepless, instant starting, compact, 50:1 speed range, good regulation without tachometer, long life, virtually maintenance free service, low cost, fast response, reversibility, dynamic brake, local or remote control. Write for Bulletin S580-5-55.

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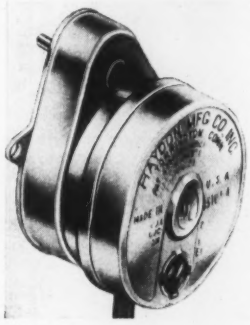
For More Information Circle Item Number on Yellow Card—page 19

New Parts



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—Circle ITEM 468

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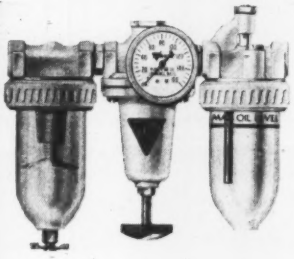

AL CHROMIUM-MANGANESE LOW-NICKEL STAINLESS GRADES

Here is a direct answer to the recurring problem of nickel shortage. For many users of chromium-nickel austenitic stainless steels, the new AISI 200-series of chromium-manganese low-nickel austenitic grades can be a source of immediate relief—and an avenue to the reduction and possible avoidance of nickel shortage problems in the future.

In many cases, you can switch directly from the older Type 301 and 302 grades to the new AL Stainless Type 201 and 202 steels, using the same fabricating processes and securing about the same results. There's nothing new to learn, and no loss in performance in practically all applications. In certain respects, these steels have better properties than the older materials and may be used to actual advantage in some cases.

We also produce low carbon grades of these chrome-manganese steels, arbitrarily designated Types 204 and 204L (similar to the older grades 304 and 304L) . . . as well as a lower-chromium, higher-manganese grade designated Type CM, which contains only 1% nickel. Allegheny Ludlum has pioneered in the development and application of these low-nickel stainless steels. We know what the new grades will do . . . let us help you put them to use. *Allegheny Ludlum Steel Corporation, Oliver Bldg., Pittsburgh 22, Pa.*

WRITE FOR THE ASSISTANCE YOU NEED

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. . . essential information on the composition, properties, fabricating methods and applications of AL chromium-manganese, low-nickel stainless steels. *Write for your copy.*

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WSW 8738

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—ITEM 558—

For More Information Circle Item Number on Yellow Card—page 19

COOPER ALLOY

CORPORATION BRIEFS

• Edited by GEORGE BLACK

DOUBLE-D REFINER

The Jones Double-D Refiner is said to bring an entirely new concept to the preparation of stock for the paper machine. Key to the design lies in the twin refining area with its double discs. For a more complete story ask for the February issue of Cooper Alloy NEWSCAST.

WHAT'S IN A TRADEMARK

Behind the Cooper Alloy trademark, cast or stamped into our stainless steel fittings, stands more than a quarter century of experience and the most complete production facilities in the industry. When you specify Cooper Alloy fittings you can be sure that every step from design to shipment is under the supervision of specialists. Look for the CA trademark before you buy . . . it is a sign of quality, experience and reliability.

DESIGN FEATURES FEATURED

Design features that have made the Cooper Alloy stainless steel valve the preferred valve for chemical processing are presented in the current issue of NEWSCAST. Diagrams and text combine to make a thorough presentation. Additional copies available on request.

NEW PUMP IN DEMAND

The new line of stainless steel rotary pumps announced by our Vanton Pump Division has taken the field by storm because it is the one (and only) pump of its kind without stuffing boxes or shaft seals. Bulletin VP561 gives the facts. Write for it today.

COOPER ALLOY
CORPORATION • HILLSIDE, N.J.

—ITEM 553—

New Parts

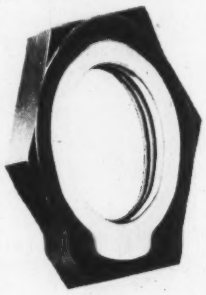
ditioners, unit heaters and coolers, furnace blowers and window fans, and are guaranteed for five years. **Westinghouse Electric Corp.**, P. O. Box 2099, Pittsburgh 30, Pa.

—Circle ITEM 464

Seal Fitting

stops leaks at threaded connections

This seal fitting, designed to eliminate leaks at pipe-thread connections without the use of sealing



compounds, is applicable to all fluid lines, such as those carrying oil, water, air, steam or chemicals. Operating temperature range is −280 F through 500 F, and pressure rating is up to 3000 psi. It is especially recommended for use where leakproof operation is essential, where pipe compounds may impair circuit operation, and on fittings that require frequent take-down and re-assembly. Sizes are available to fit the majority of piping installations. **Flick-Reedy Corp.**, Tru-Seal Div., 2040 N. Hawthorne Ave., Melrose Park, Ill.

—Circle ITEM 465

Four-Pole Relay

for machine-tool applications

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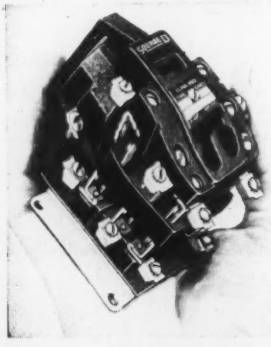

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TITLE _____

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CITY _____ ZONE ____ STATE _____

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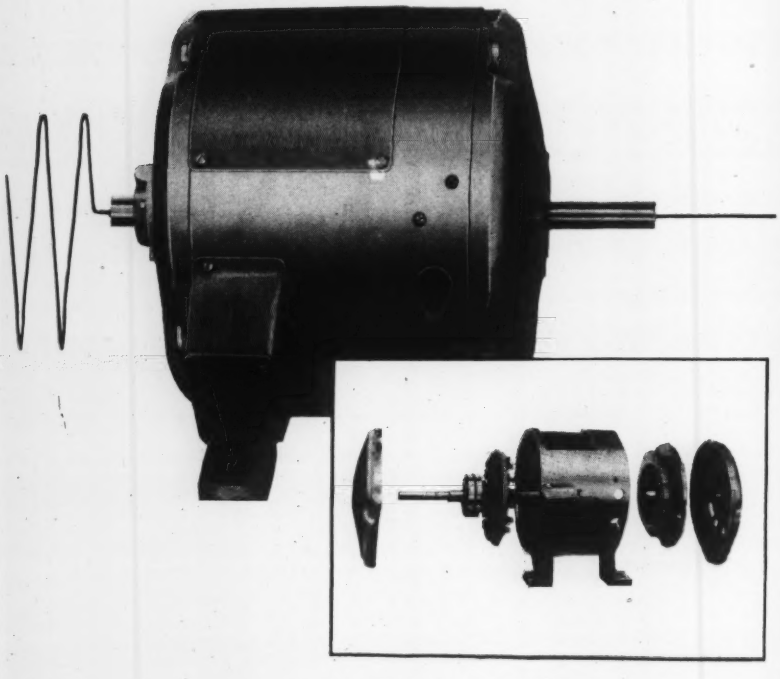

rotary rectifier for speed control

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ESCO ELECTRIC SPECIALTY CO.

179 South Street, Stamford, Conn.

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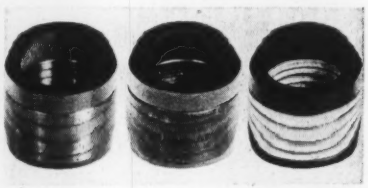

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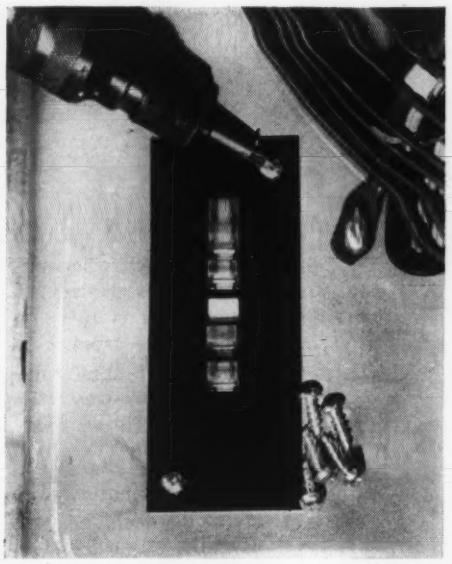

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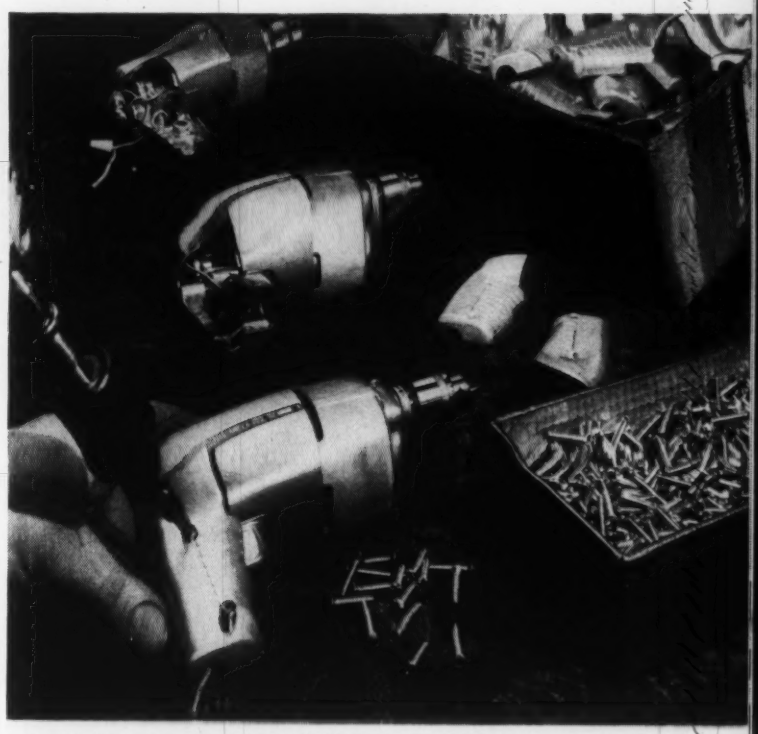

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X marks the spot
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Members of Screw Research Association

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Magnetic Amplifiers · INC

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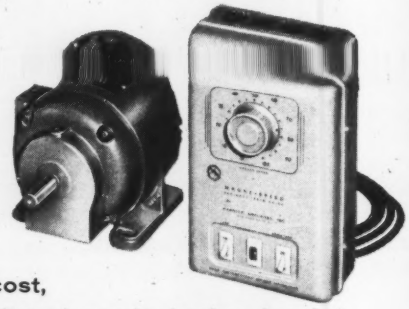

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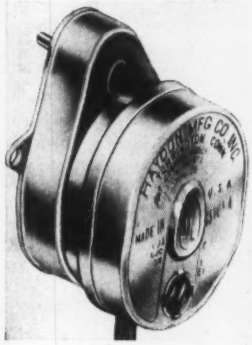
New Parts



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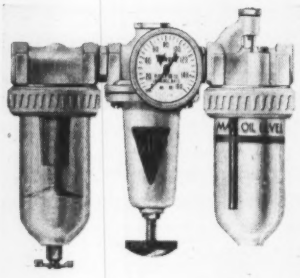

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Here is a direct answer to the recurring problem of nickel shortage. For many users of chromium-nickel austenitic stainless steels, the new AISI 200-series of chromium-manganese low-nickel austenitic grades can be a source of immediate relief—and an avenue to the reduction and possible avoidance of nickel shortage problems in the future.

In many cases, you can switch directly from the older Type 301 and 302 grades to the new AL Stainless Type 201 and 202 steels, using the same fabricating processes and securing about the same results. There's nothing new to learn, and no loss in performance in practically all applications. In certain respects, these steels have better properties than the older materials and may be used to actual advantage in some cases.

We also produce low carbon grades of these chrome-manganese steels, arbitrarily designated Types 204 and 204L (similar to the older grades 304 and 304L) . . . as well as a lower-chromium, higher-manganese grade designated Type CM, which contains only 1% nickel. Allegheny Ludlum has pioneered in the development and application of these low-nickel stainless steels. We know what the new grades will do . . . let us help you put them to use. *Allegheny Ludlum Steel Corporation, Oliver Bldg., Pittsburgh 22, Pa.*

WRITE FOR THE ASSISTANCE YOU NEED

1. "TECHNICAL STUDIES #3"

. . . essential information on the composition, properties, fabricating methods and applications of AL chromium-manganese, low-nickel stainless steels. *Write for your copy.*

2. TEST SAMPLES

. . . We'll be glad to supply engineering assistance, and actual samples of these 200-Series steels for testing under your processes and conditions.

ADDRESS DEPT. MD-78

For Stainless Steel in ALL Forms—call

Allegheny Ludlum

AL STAINLESS STEEL

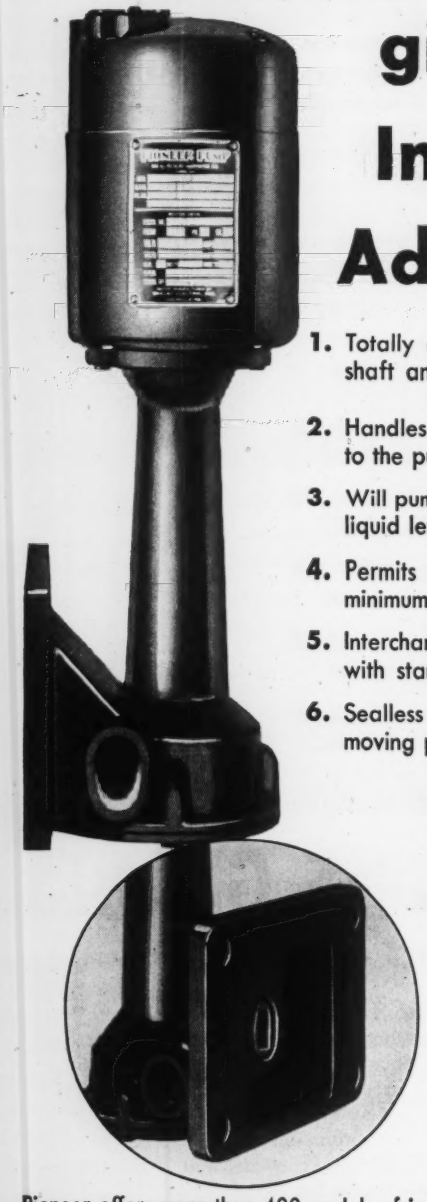
WSW 8738

Warehouse stocks carried by all Ryerson Steel plants

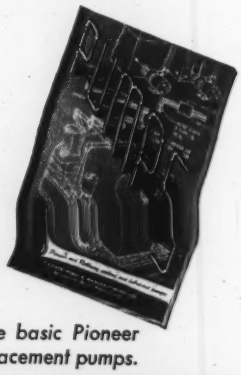
—ITEM 558—

For More Information Circle Item Number on Yellow Card—page 19

This New PIONEER Coolant Pump gives you Important Advantages



1. Totally enclosed motor, with extra-heavy shaft and heavy-duty ball bearings.
2. Handles abrasives or chips without injury to the pump.
3. Will pump down to 1 1/16"; self-priming to 1" liquid level.
4. Permits clean-out of machine sump with minimum time and labor.
5. Interchangeable with any make pump with standard mounting dimensions.
6. Sealless design with no metal-to-metal moving parts.
7. Can be furnished with any desired electrical characteristics.
8. Three optional outlets: left external, right external, center outlet through mounting flange. The latter permits compact, clean-cut design of machine with no exposed piping.



Pioneer offers more than 400 models of impeller-type and positive displacement pumps to meet every coolant pump requirement; or we will develop designs for specific applications. Our application engineers will welcome the opportunity to discuss your pump requirements with you.

Send for our illustrated booklet covering the basic Pioneer designs in both impeller-type and positive displacement pumps.

PIONEER PUMP DIVISION
DETROIT HARVESTER COMPANY
Sales Office: 5450 West Jefferson Ave., Detroit 9, Michigan
Plant: Paris, Kentucky

New Parts

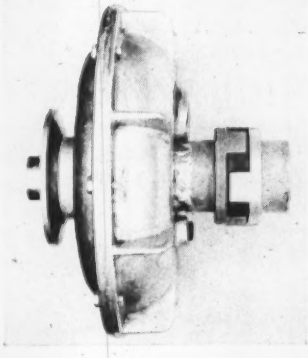
in sizes ⅛ through ½-in. for general-purpose, high-capacity, low-pressure and precision control can also be supplied. They have two, three or four-way body connections. **Watts Regulator Co.**, 10 Embankment St., Lawrence, Mass.

—Circle ITEM 469

Hydraulic Coupling

gives smooth power for fractional-hp applications

Applicable to equipment requiring absorption of running shocks and torsional vibration, torque limita-



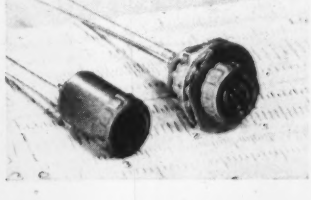
tion, smooth starting or plug reversing, this hydraulic coupling transmits up to ¾ hp at 1750 rpm. It is available with an integral V-belt sheave or a flexible coupling for direct drive. Model F is 7¼ in. OD and weighs approximately 2 lb when filled with oil. Typical applications include conveyors, door operators and cranes. **Fluid Drive Engineering Co.**, 3105 E. Cheltenham Place, Chicago 49, Ill.

—Circle ITEM 470

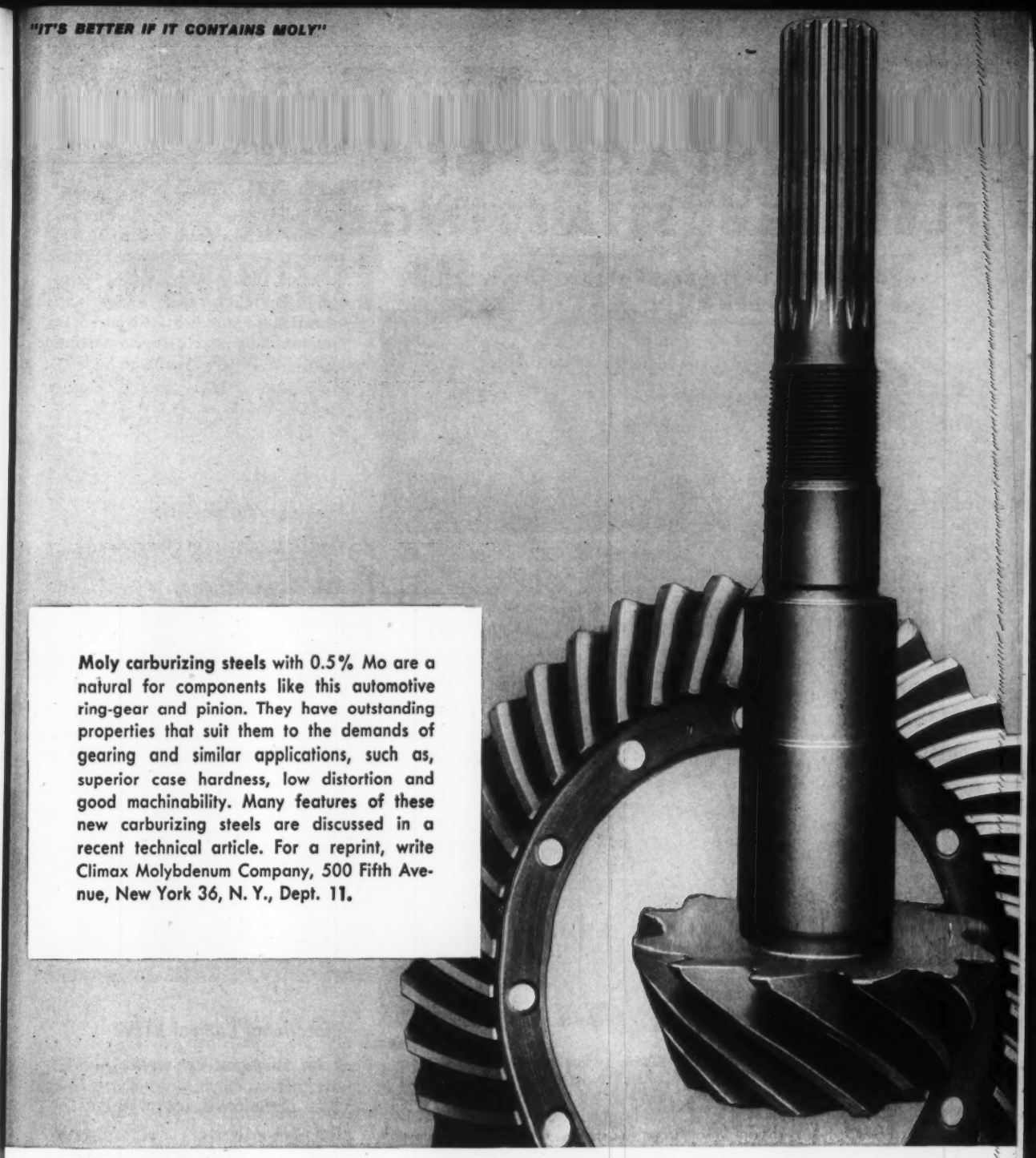
Trimmer Potentiometers

have 100 to 15,000 ohm resistance range

Allowable ambient temperature range of these potentiometers permits ¼-w power rating up to 87.5 C. Power rating is linearly derated to zero at 150 C, with a rating of 1/10-w at 125 C. Using 20



"IT'S BETTER IF IT CONTAINS MOLY"



Moly carburizing steels with 0.5% Mo are a natural for components like this automotive ring-gear and pinion. They have outstanding properties that suit them to the demands of gearing and similar applications, such as, superior case hardness, low distortion and good machinability. Many features of these new carburizing steels are discussed in a recent technical article. For a reprint, write Climax Molybdenum Company, 500 Fifth Avenue, New York 36, N. Y., Dept. 11.

Molybdenum Carburizing Steels

MOLYBDENUM OFFERS THE ECONOMICAL KEY TO PERFORMANCE

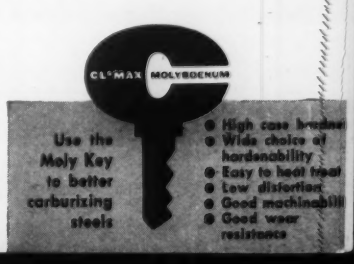
Over the years, molybdenum carburizing steels have proved their merits in scores of applications and at every level of production.

Design engineers know moly steels for their uniform hardenability, toughness and wear resistance.

Production men know that moly steels are easy to heat treat, easy to machine.

Management knows that moly steels mean economy in fabrication, high performance in a wide range of end products.

Standard molybdenum carburizing steels are widely available. Higher moly analyses may be ordered in heat lots from a number of leading suppliers.



CLIMAX MOLYBDENUM

(Advertisement)

ADVANTAGES OF FLEXIBLE SHAFTING

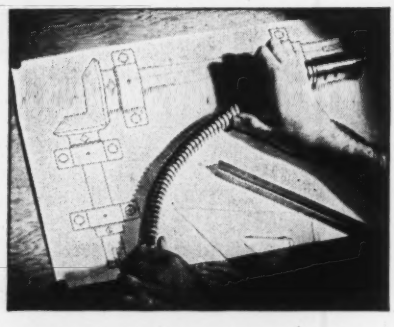
For Power Drive and Remote Control

by

C. Hotchkiss, Jr.

Application Engineer

Stow Manufacturing Company



Flexible shafting has the following advantages over other type drives:

1—it is often the simplest method of transmitting power between two points which are not collinear or which have relative motion

2—eliminates exposed revolving parts

3—does not require accurate alignment

4—easy to install and maintain

Not Collinear—Where it is necessary to connect two shafts which are not collinear, a simple arrangement of a single belt or two universal joints will often do the job adequately. But, in many cases where the path of transmission is more complicated and would require a more expensive arrangement of mechanical components, flexible shafting provides a simple, low cost, efficient drive which is easy to install because it does not require accurate alignment. See example, figure 1, in which a 1¼-inch Stow flexible shaft is used to drive the auger on a G.L.F. bulk feed truck.

Flexible shafting also allows the designer greater freedom in locating either the drive or the driven component on a piece of equipment.

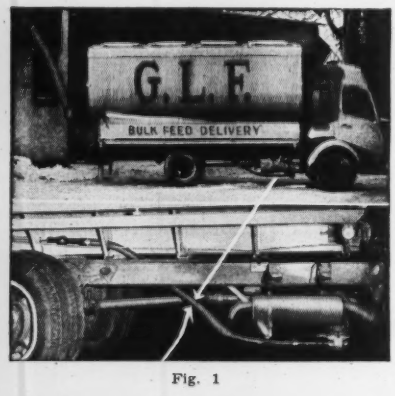


Fig. 1

Relative Motion — Where two shafts which have relative motion must be connected, flexible shafting is often the ideal means of transmission. In many cases it eliminates a much more complicated drive which would, necessarily, include telescopic joints; further, it eliminates the danger of exposed moving parts. See figure 2, which shows a ¾-inch Stow flexible shaft driving an Avery Rake built by the Minneapolis Moline Co.

Fig. 2

Other typical applications of this type are used on portable power tools when motors are too heavy to be mounted on the tool—such as portable grinders, sanders, paint scrapers, saws and tree tappers. And, since flexible shafting is not affected by vibration, it is an ideal drive for applications where a high degree of vibration is involved—such as in vibration testing tables and concrete vibrators.

Stow flexible shafts are available: for power drive applications in diameter sizes from ⅛-inch to 1¼-inches; for remote control applications in diameter sizes from ⅛-inch to 1⅝-inches. The 1¼-inch power drive shaft will transmit up to 10 HP while the 1⅝-inch remote control shaft will transmit up to 4000 lb. in.

For complete engineering data on flexible shafting, including selection charts, write for engineering bulletin 525.

STOW MANUFACTURING COMPANY

11 SHEAR STREET • BINGHAMTON, NEW YORK

—ITEM 561—

For More Information Circle Item Number on Yellow Card—page 19

New Parts

PPM resistance wire, the potentiometers are supplied with resistance values from 100 to 15,000 ohms in 14 standard values. Withstanding 30 *g* shock, they pass rigid humidity, salt spray and vibration requirements. Housed in dimensionally stable thermosetting plastic, they are available in cylinder and bushing mount types. **Carter Mfg. Corp.,** 23 Washington St., Hudson, Mass.

—Circle ITEM 471

Precision-Rolled Strip

held to 0.0001-in. tolerance

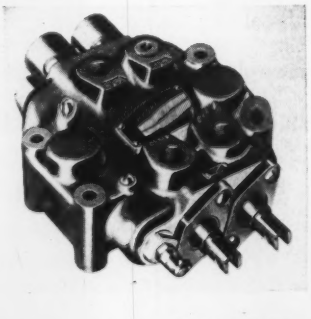
For close-tolerance assemblies in electrical, electronic and instrument components, precision-rolled thin metal strip is available in thicknesses from 0.001-in., and is held to tolerances as close as ±0.0001 in. Maximum widths of 4 in. can be processed and, after rolling, can be slit to any desired width. Strips of silver, silver alloy, brass, copper and other alloys can be supplied by the fabricator or customer material can be rolled on a fee arrangement. **Handy & Harman,** 82 Fulton St., New York, N. Y.

—Circle ITEM 472

Directional Control Valve

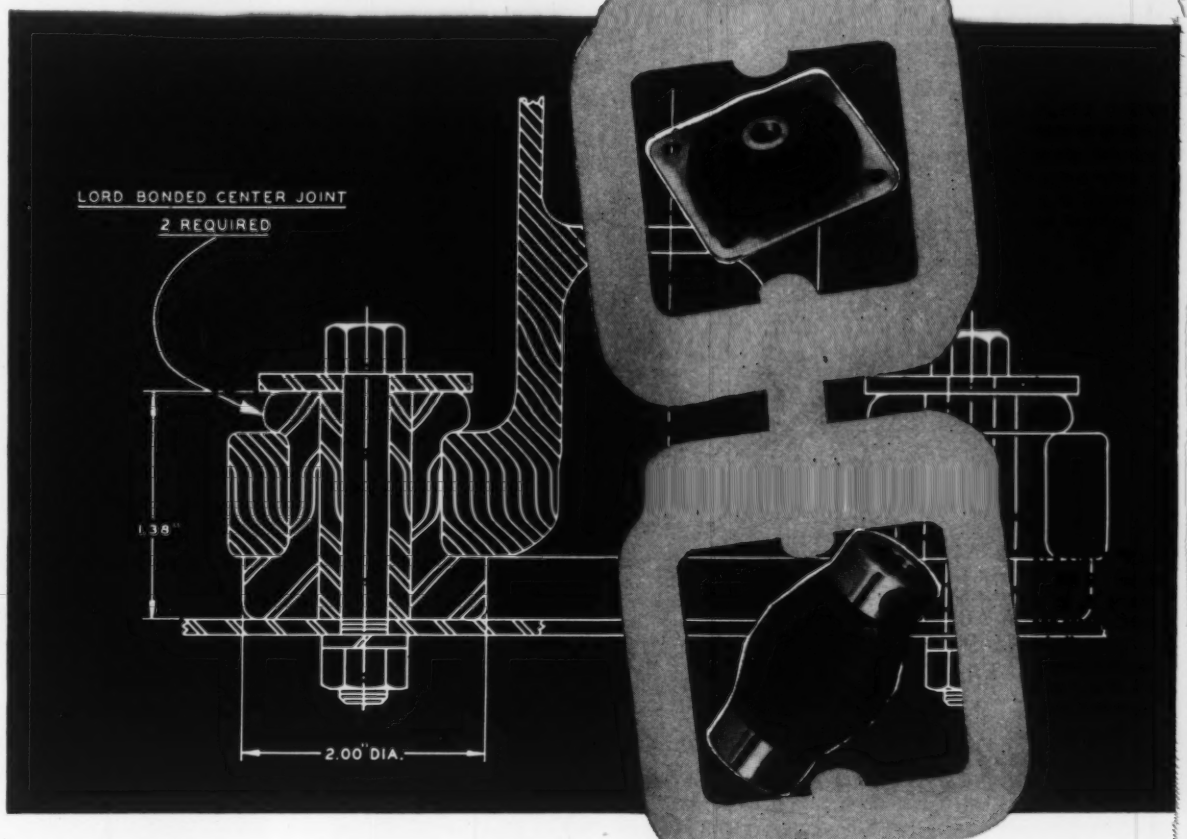
for fluid-power circuits

This directional control valve for fluid-power circuits, Hydreco series V-32, is for application on materials handling equipment and other mobile units. It has an integral pilot-operated relief and unloading valve, and parallel circuits to afford simultaneous connection of the pressure port to any number of cylinders. Five models are available, offering from two to six operating plungers. Rated capacity



LORD CONTROLS VIBRATION . . . ANYWHERE!

THE MOST POSITIVE BOND OF PRODUCT TO PERFORMANCE



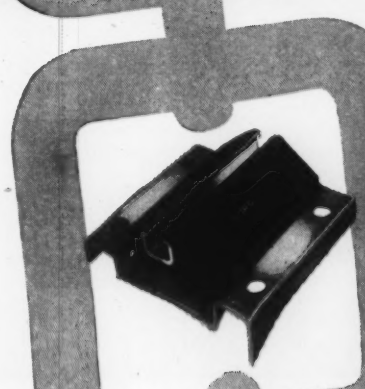
Vibration control is a vital element of improved product performance . . . and the most positive way to control vibration is through LORD Bonded-Rubber Mountings. Here are several outstanding reasons why:

Isolate Vibration — Stop noise transmission or vibration caused by moving mechanical components.

Lengthen Product Life — minimize stresses caused by shaft misalignment or torsional vibration.

Reduce Maintenance Expense — the rubber element absorbs flexing action . . . no surfaces to wear or chafe . . . no lubrication is needed.

LORD maintains a staff of vibration engineers to assist manufacturers in isolating destructive vibration. They will gladly assist you by designing and producing the most economical and efficient mounting for your needs. Call or write the LORD Mfg. Co., Erie, Pa.



CHAN-L-MOUNTS provide excellent reduction of steady vibrations and occasional shock problems. Designed to provide maximum deflection for their size.

LORD MANUFACTURING COMPANY • ERIE, PENNSYLVANIA

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LORD

DESIGNERS AND PRODUCERS OF BONDED RUBBER PRODUCTS SINCE 1924